USEPA Regulatory Update

Lead and Copper Rule Revisions

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Overview

- History of LCR Revisions
- Updates on Science
  - Lead Health Effects
  - Sampling Site Selection
  - Sampling Protocol
  - Treatment
- Summary

Lead and Copper Rule Rulemaking History

History of LCR Revisions

- Original Lead and Copper Rule was promulgated in 1991
  - Many studies have been conducted since 1991 on LCR-related topics, including corrosion and corrosion control
  - Lessons learned from systems attempting to simultaneously comply with multiple NPDWRs
- Several revisions have been made to the rule since 1991
  - LCR Minor Revisions in 2000
  - LCR Short-term Revisions in 2007
- Significant issues left for LCR 'Long-term' revisions

LCR Long-Term Revisions (LCR-LTR)

- Potential Changes to Lead and Copper Rule
  - Sample site selection criteria (lead and copper)
  - Sampling procedures for lead and copper tap monitoring
  - Public education for lead and copper
  - Corrosion control treatment & process control
  - Lead service line replacement requirements
  - Remove/revise outdated requirements
  - Streamline rule requirements for systems
  - Other Issues

NDWAC Consultation

- National Drinking Water Advisory Council (NDWAC) Meetings
  - Optimal Corrosion Control Treatment (March 25-26. 2014)
  - Sample Site Selection (May 29-30, 2014)
  - Sampling Protocol (Sept 18-19, 2014)
  - Lead Service Line Replacement (Nov 12-13, 2014)

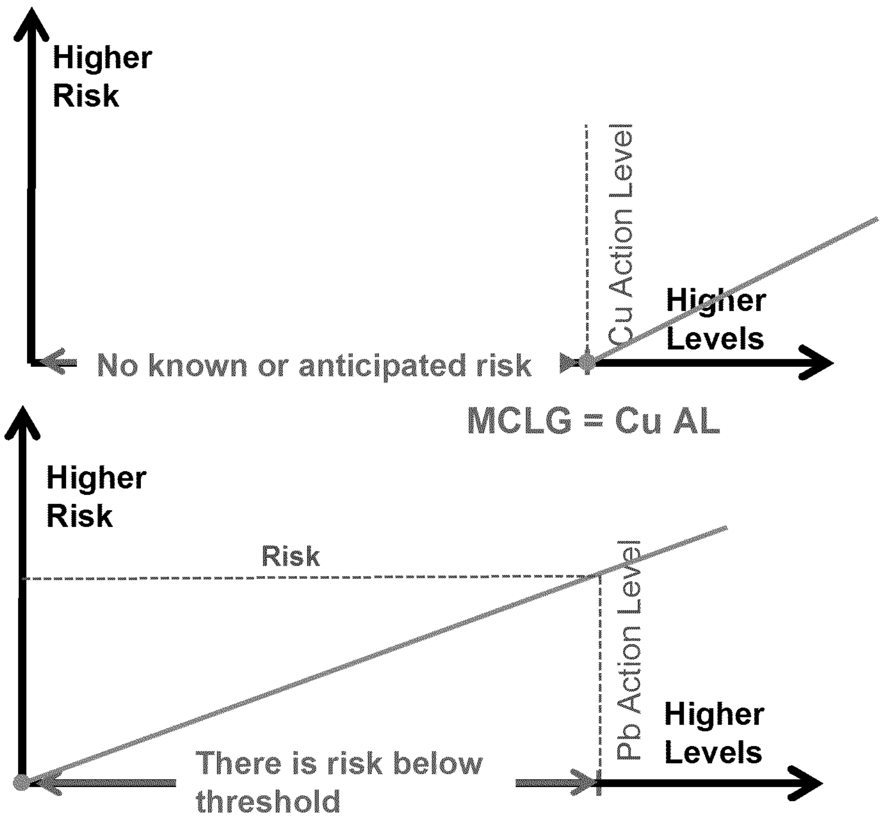
Updates on Science

Health Effects

What is the Pb ‘Action Level’?

- **The Pb action level is NOT health-based**
  - It’s not a threshold level that separates safe and unsafe Pb levels
  - EPA and CDC Risk Assessments:
    - There is no safe level of exposure to lead.
    - Infants, children and pregnant women should avoid all exposure to lead.
  - EPA’s lead action level is a threshold value which requires public water systems to ***take action*** to reduce consumers lead exposure if lead levels exceed the lead ‘action level’ of 15 ppb.
    - Set at 15ug/L in 1991 based on EPA’s understanding of the existing treatment capabilities and treatment costs at that time (i.e., achievable level)

Explaining The Risk



When MCLG = specified value (<u>not zero</u>) = no known or anticipated adverse health effects occur below that value.

The Pb action level is above the health-based MCLG of zero, and so there is a risk from lead exposure below EPA's Pb action level.

MCLG for Pb = 0: No level without known or anticipated adverse health effects; Pb AL = 15 µg/L

Centers for Disease Control and Prevention (CDC) – on lead in DC water

"Controlling for age of housing, LSL was an independent risk factor for BLLs ≥10 mg/dL, and ≥5 mg/dL even during time periods when water levels met the US Environmental Protection Agency (EPA) action level of 15 parts per billion (ppb)."

- Childhood lead poisoning prevention programs should be made aware of the results of local public water system lead monitoring measurement under LCR and consider drinking water as a potential cause of increased BLLs, especially when other sources of lead exposure are not identified.
- When investigating cases of children with BLLs at or above the reference value established as the 97.5 percentile of the distribution of BLLs in U.S. children aged 1–5 years, drinking water should be considered as a source.

Low Lead Level Exposure Harms Children:
A Renewed Call for Primary Prevention (January 4, 2012)

Advisory Committee on Childhood Lead Poisoning Prevention (ACCLPP) ***of the Centers for Disease Control and Prevention***

- Reaffirmed there is no safe level of lead exposure.
- Recommended eliminating term 'blood lead level of concern' – replaced with 'reference value' (currently 5ug/dL) to emphasize that there is no safe level.
- Reaffirmed the best way to protect children is to prevent lead exposure in the first place.

"In January 2012, a committee of experts recommended that the CDC change its "blood lead level of concern." The recommendation was based on a growing number of scientific studies that show that even low blood lead levels can cause lifelong health effects."

http://www.cdc.gov/nceh/lead/acclpp/final_document_030712.pdf

Fetal Death and Reduced Birth Rates Associated with Exposure to Lead-Contaminated Drinking Water

- Fetal death rates (FDR) in Washington DC (1997-2004) peaked in 2001 when water lead levels (WLLs) were highest.
- FDR were minimized in 2004 after public health interventions were implemented to protect pregnant women.
- Birth rates in DC increased versus Baltimore City and versus the United States in 2004-2006, when consumers were protected from high WLLs.
- After public health protections were removed in 2006, DC FDR spiked in 2007-2009 versus 2004-2006 in a manner consistent with high WLL arising from partial lead service line replacements.

http://pubs.acs.org/doi/full/10.1021/es4034952

Fetal Death and Reduced Birth Rates Associated with Exposure to Lead-Contaminated Drinking Water

- DC FDR dropped to historically low levels in 2010-2011 after consumers were protected and the PSLR program was terminated.
- Re-evaluation of construction-related miscarriage cluster in the USA Today Building (1987-1988), demonstrates that high WLLs from disturbed plumbing were a possible cause. Overall results are consistent with prior research linking increased lead exposure to higher incidence of miscarriages and fetal death, even at blood lead elevations (≈ 5 ug/dL) once considered relatively low.

http://pubs.acs.org/doi/full/10.1021/es4034952

Lead & Element Percentages in Corrosion Byproduct Solids

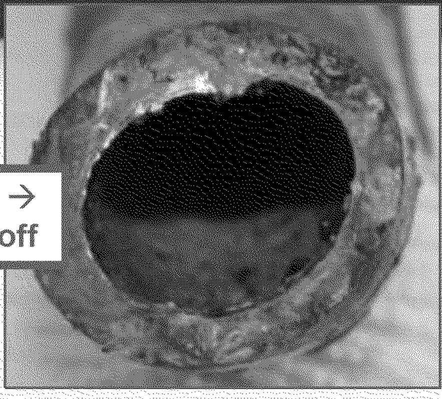
Lead & Element Percentages in Important Corrosion Byproduct Solids							
Mineral Name	Formula	% Pb	%C	%O	%S	% P	%Cl
litharge, massicot	PbO	**97.80**	0.00	7.20	0.00	0.00	
plattnerite, scrutinyite	PbO_2	**86.60**	0.00	13.40	0.00	0.00	
Cerussite	$PbCO_3$	**77.50**	4.50	18.00	0.00	0.00	
Hydrocerussite	$Pb_3(CO_3)_2(OH)_2$	**80.10**	3.10	16.50	0.00	0.00	0.00
Plumbonacrite	$Pb_{10}(CO_3)_6(OH)_6O$	**81.30**	2.80	15.70	0.00	0.00	0.00
Anglesite	$PbSO_4$	**68.30**	0.00	21.10	10.60	0.00	0.00
Leadhillite, Susannite, MacPhersonite	$Pb_4(SO_4)(CO_3)_2(OH)_2$	**76.80**	2.20	17.80	3.00	0.00	0.00
Hydroxypyromorphite	$Pb_5(PO_4)_3OH$	**77.43**	0.00	15.55	0.00	6.95	0.00
Chloropyromorphite	$Pb_5(PO_4)_3Cl$	**76.38**	0.00	14.15	0.00	6.85	2.61
Tertiary Lead Orthophosphate	$Pb_3(PO_4)_2$	**76.60**	0.00	15.80	0.00	7.60	0.00
Lead(II) orthophosphate	$Pb_9(PO_4)_6$	**76.60**	0.00	15.80	0.00	7.60	0.00

The federal definition of lead-based paint is 0.5 percent lead (0.5%).

Lead Service Line Disturbances

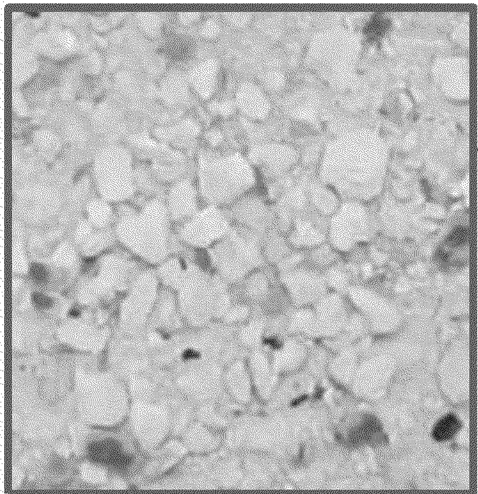
Partial LSL Replacement

LSL disturbance → Scale has fallen off



Physical LSL Disturbances Can Dislodge High-Pb Scale and Sediment

These disturbances occur on a daily basis during infrastructure work.



Sediment/Scale → Primarily Aluminum, Phosphorous & Calcium

- 330,000 µg/L Pb in particulate sample
- 125,000 µg/L Pb in suspended sample

Lead service line disturbances were found to be a common factor for the majority of sites with high lead levels. It is also possible that low water usage may play a role in sites with the highest lead levels.

Public Education / Risk Communication

- Residents with LSLs should be alerted to the risks posed by LSLs
- PWSs should not assure residents that the water is safe to drink when it is not
  - Not an accurate statement
  - Residents will not take measures to protect their families
- Notify residents of risks from particulate lead and scale/sediment release from LSL disturbances
- Thoroughly flush the lines following LSL disturbances and provide flushing and aerator cleaning instructions to residents when LSLs are disturbed

Sampling Site Selection

Sources of Lead in Drinking Water

- Lead service lines
  - Largest single source of lead in distribution system where present
  - Millions installed in many systems throughout U.S. going back over 100 years ago
  - Very durable: 100+ yr old LSLs are still in service and have not degraded.
- **Leaded brass (brass meters, faucets, valves, connectors, couples, etc.)**
  - Commonly found in most homes
  - Lead content and leaching potential varies significantly
  - Devices meeting 0.25% on wetted surface began to emerge with CA and VT legislation before 2011 SDWA Amendments.
  - Significance will decline over time as existing devices are replaced with 2014-compliant devices, but can still be a factor in the near term
- **Leaded solder**
  - Common in homes built prior to SDWA use prohibition in 1986
  - Significance continues to diminish with time

Lead Release Mechanisms

Water Quality Factors

- **Corrosive/Aggressive Water Quality**
  - Corrosive/Aggressive water can dissolve lead into the water and cause release of lead particles
- **Water Chemistry**
  - Iron and Manganese can sorb lead and transport it into home plumbing ('seeds' home plumbing with lead)
  - Natural Organic Matter (NOM) in source water can increase lead release
  - Chloride-to-Sulfate Mass Ratio can increase galvanic corrosion.
  - Chemistry of water varies and can change over time
    - Can affect the composition and stability of scales within LSLs and lead release

Lead Release Mechanisms
Physical and Chemical Disturbances

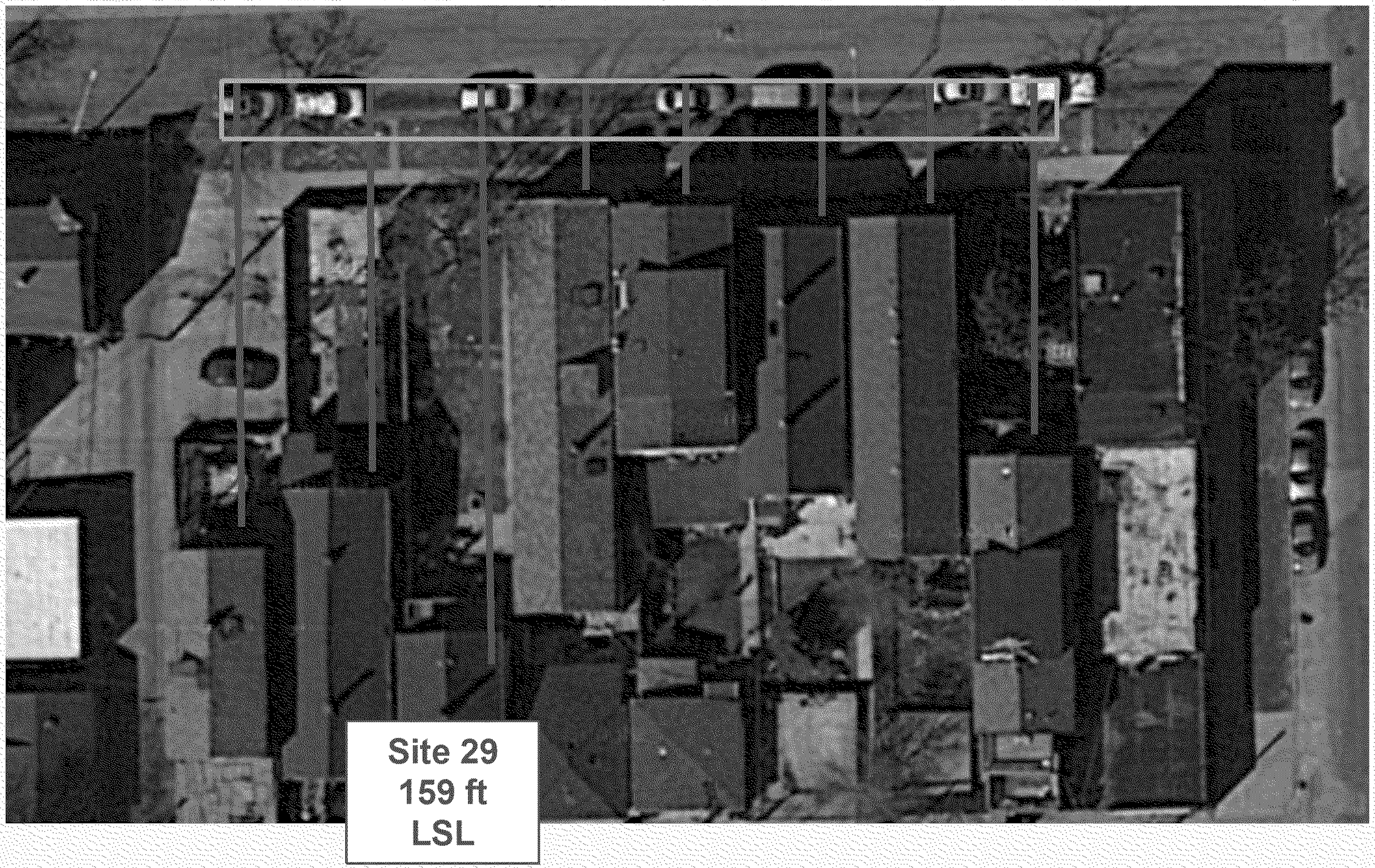
- **Physical and chemical disturbances of LSL scales can cause lead to dissolve into water and/or particulate lead release into the water**
  - Water chemistry changes can result in high lead release system-wide*
  - Physical disturbances to LSLs can release lead-bearing scale and sediment at individual sites*
- **Galvanic Corrosion**
  - Connection of copper pipe to lead pipe during partial LSL replacement can cause galvanic corrosion of lead
    - Chloride to sulfate mass ratio can impact severity of galvanic corrosion.

***where lead sources are present**

Lead Release: Other Factors

- **Variable Length of LSLs**
  - Can vary significantly within same system
  - Longer LSLs can contribute more lead
- **Current rule allows 50% LSL sites and 50% leaded-solder sites as Tier 1 sites**
  - Sites with LSLs yield much higher results overall than non-LSL sites
- **Water Usage Varies from Site to Site**
  - Low water use homes may perpetually have high lead
  - Homes become vacant and are subsequently re-occupied
  - Stagnation can affect protective scales within LSLs
- **Particulate Lead is released sporadically**
  - Can increase with higher flow rates

Distance Between Water Main and Homes Varies Significantly



Major Variability Factors: Summary Table

Example of Realistic Site Characteristics within the Same Public Water System

Higher Risk/Lead Release Factors

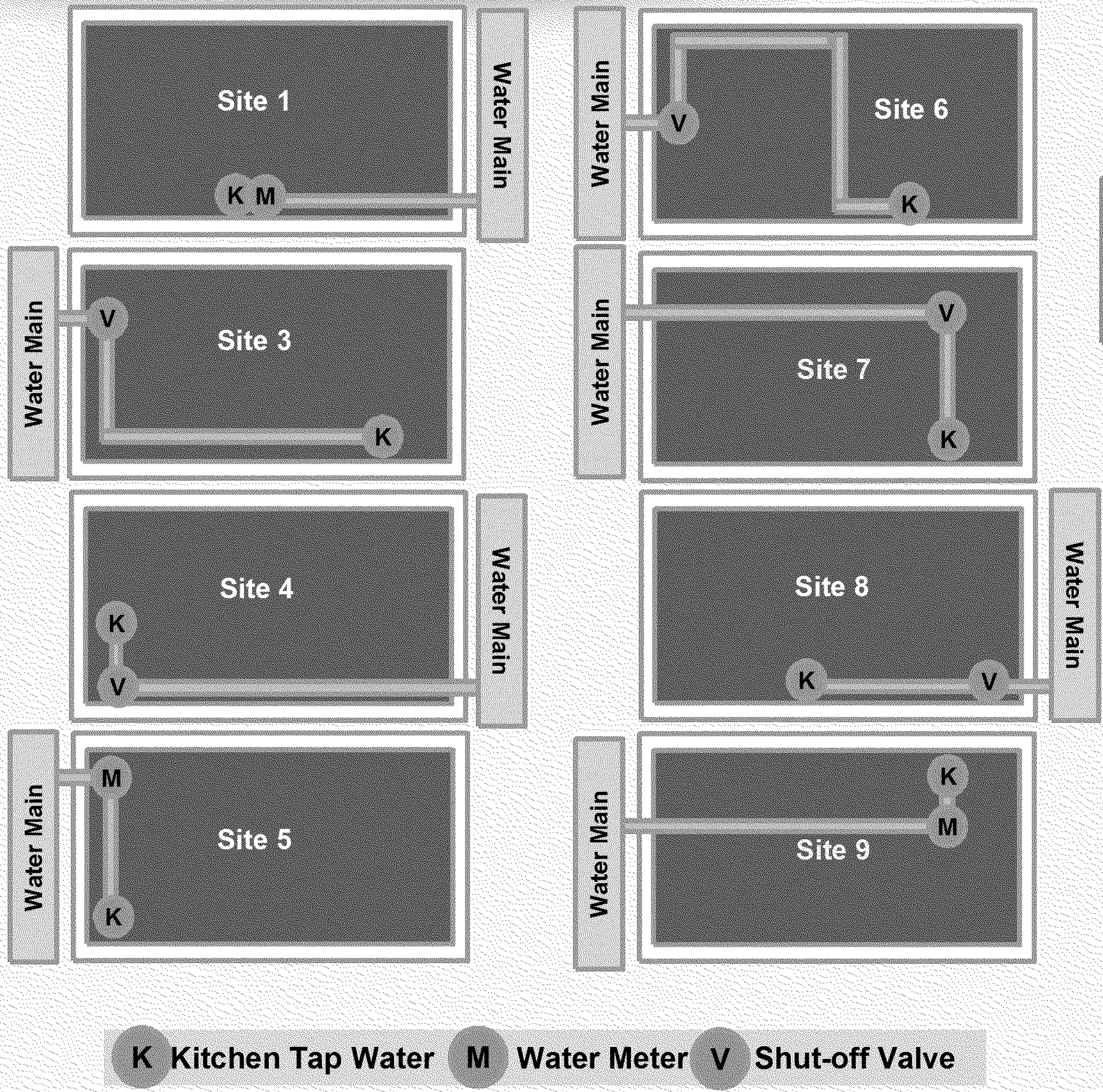
Site	Recently re-occupied	Lower water use	Disturbed LSL	Partial LSL	Longer LSL	Warmer water temps	Fe/Mn in water	Aggressive water zone
1	X	X		X		X	X	
2		X	X		X		X	
3			X		X			X
4	X			X		X		X
5		X			X		X	X
…								

Lower Risk/Lead Release Factors

Site	Continuously occupied	Higher water use	Undisturbed LSL	No LSL	No partial LSL	Shorter LSL	Colder water temps	No Fe/Mn in water	Non-aggressive water zone
6	X			X	X			X	
7	X		X		X	X	X	X	X
8	X	X		X			X	X	
9	X		X		X	X		X	X
10	X	X		X	X		X	X	
…									

Sampling Protocol

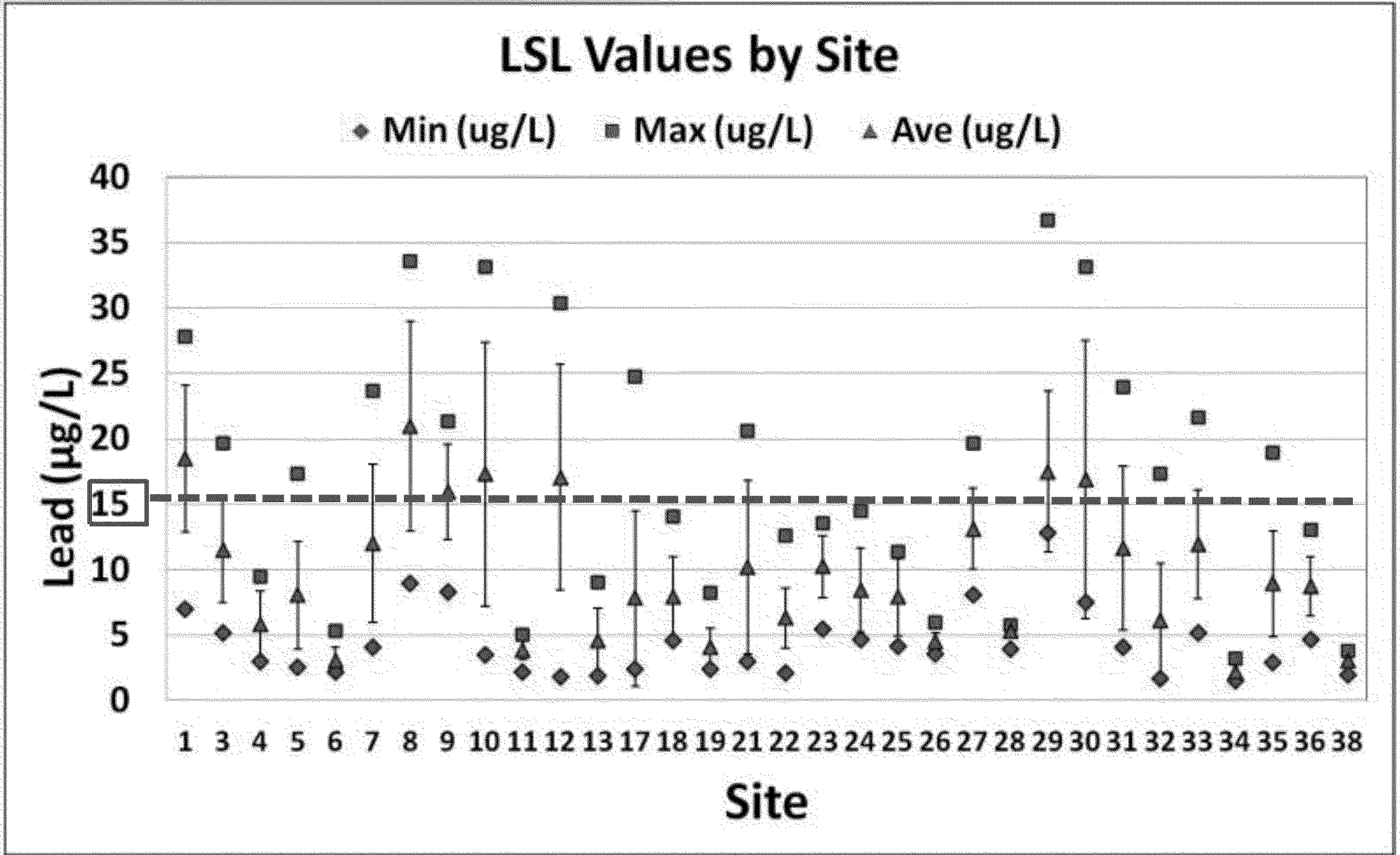
Distance Between Kitchen Taps and LSLs Varies Considerably



Plumbing configurations within each home varied significantly.

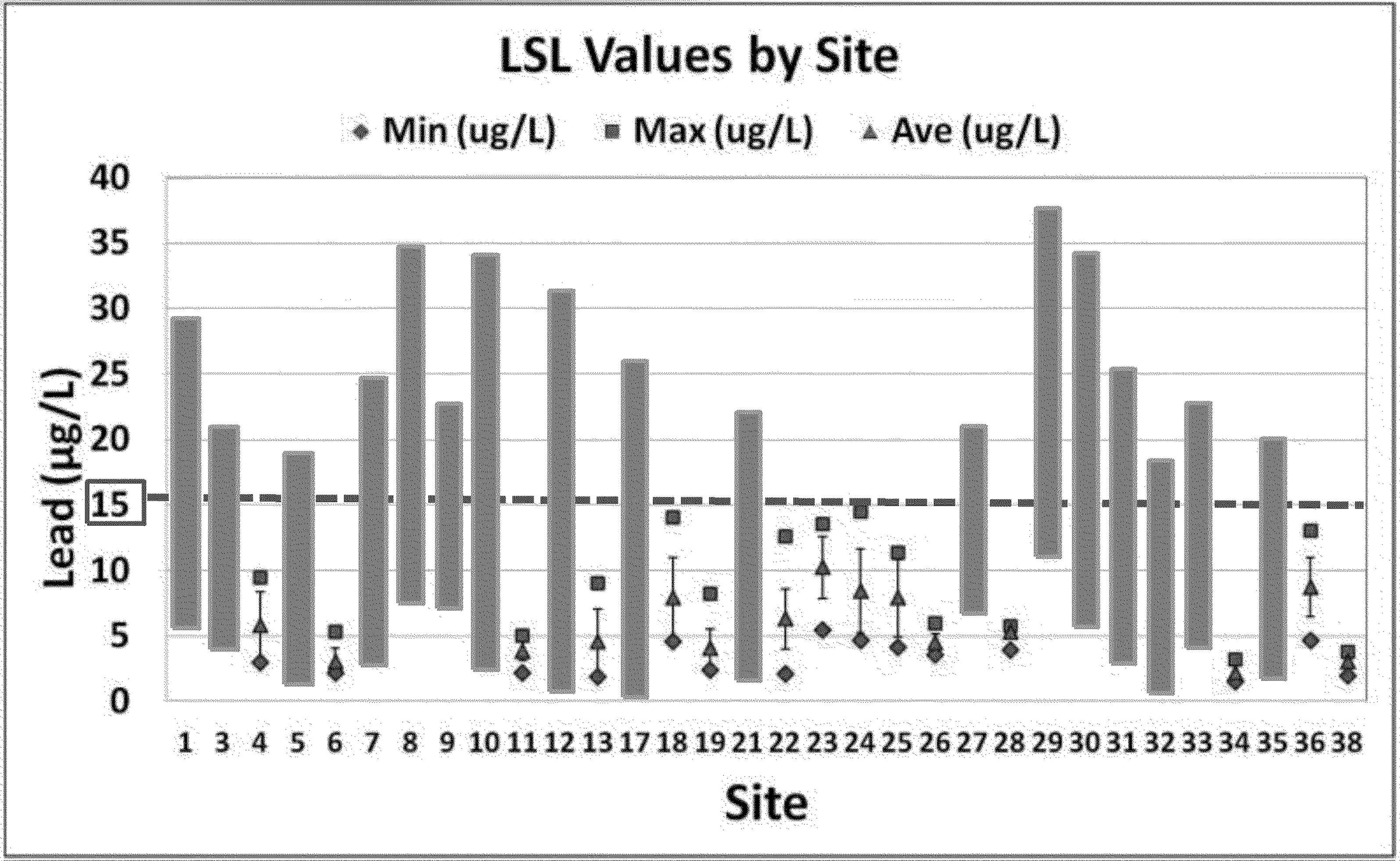
Some LSLs end just inside the front wall; Some continue beyond.

Pb is Variable Across Sites



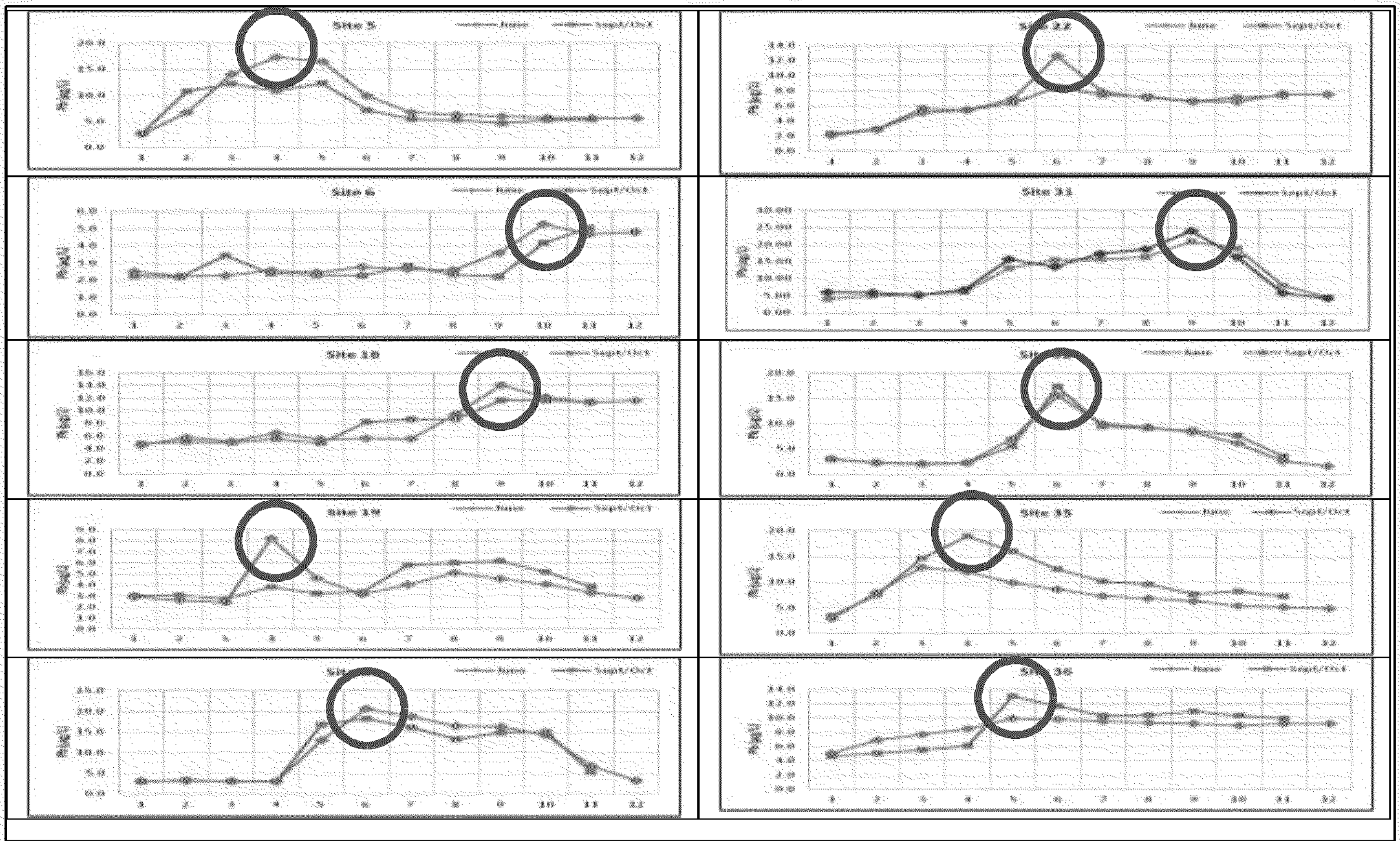
A PWS can meet or not meet the lead AL based on the sites that are selected for compliance sampling.

Pb is Variable Within Each Site



Even if the worst-case sites are chosen, a PWS can meet or exceed the lead action level based on the liter selected for the LSL sample (53% of sites in this study).

Peak Pb Occurs at Different Points



High lead levels in water can easily be missed

Using Same Liter at all Sites Misses Peak at Most/All Sites

June (28 Sites)												
If this liter is used across all sites	1st liter	2nd liter	3rd liter	4th liter	5th liter	6th liter	7th liter	8th liter	9th liter	10th liter	11th liter	12th liter
No. of sites that miss peak lead value	28	27	26	25	26	22	25	28	24	24	28	26
Percent of sites that miss peak lead value	100 %	96%	93%	89%	93%	79%	89%	100 %	86%	86%	100 %	93%

September / October (30 Sites)											
If this liter is used across all sites	1st liter	2nd liter	3rd liter	4th liter	5th liter	6th liter	7th liter	8th liter	9th liter	10th liter	11th liter
No. of sites that miss peak lead value	30	29	28	27	28	25	24	30	23	28	28
Percent of sites that miss peak lead value	100%	97%	93%	90%	93%	83%	80%	100%	77%	93%	93%

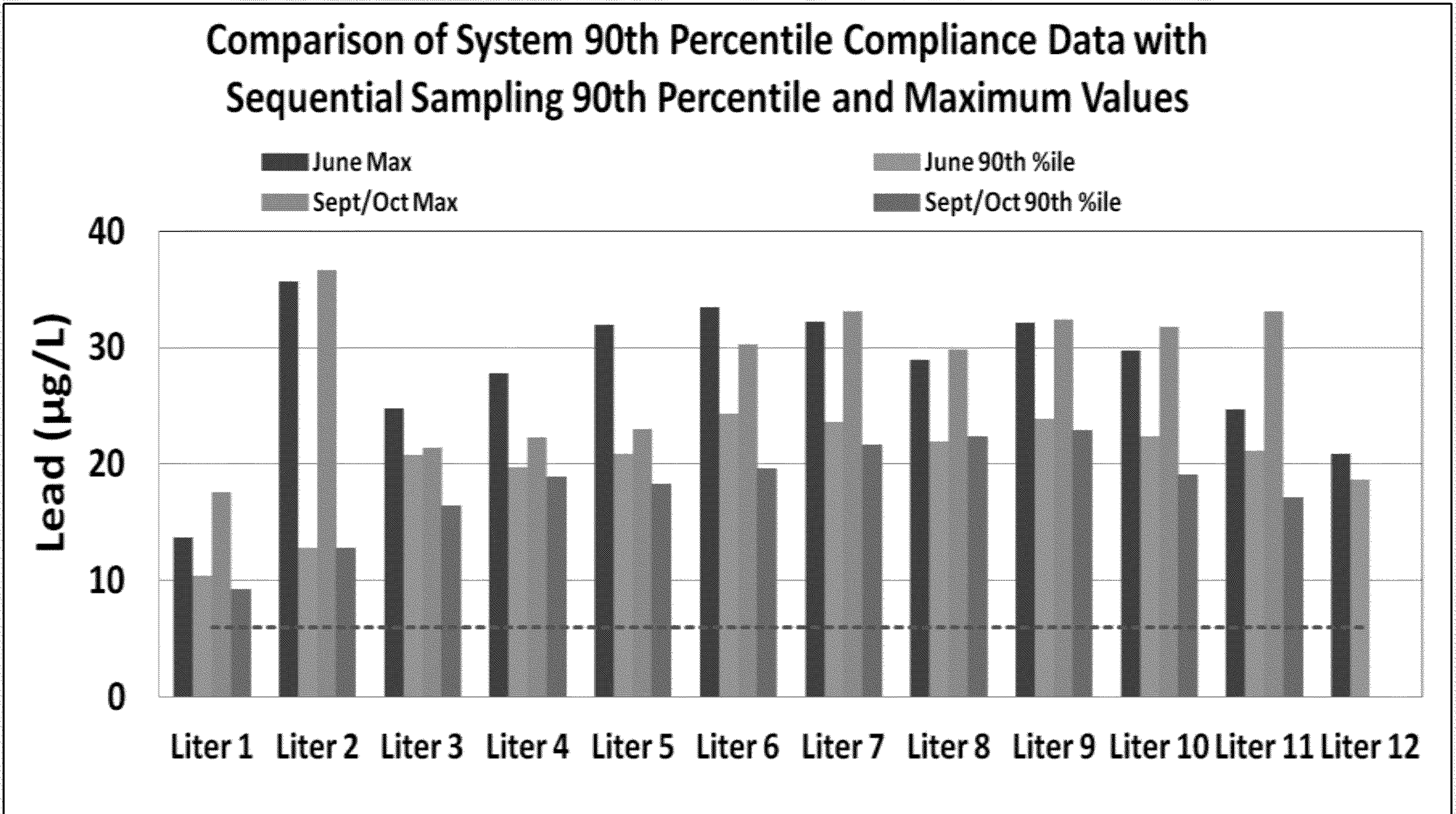
High lead levels in water can easily be missed

Treatment

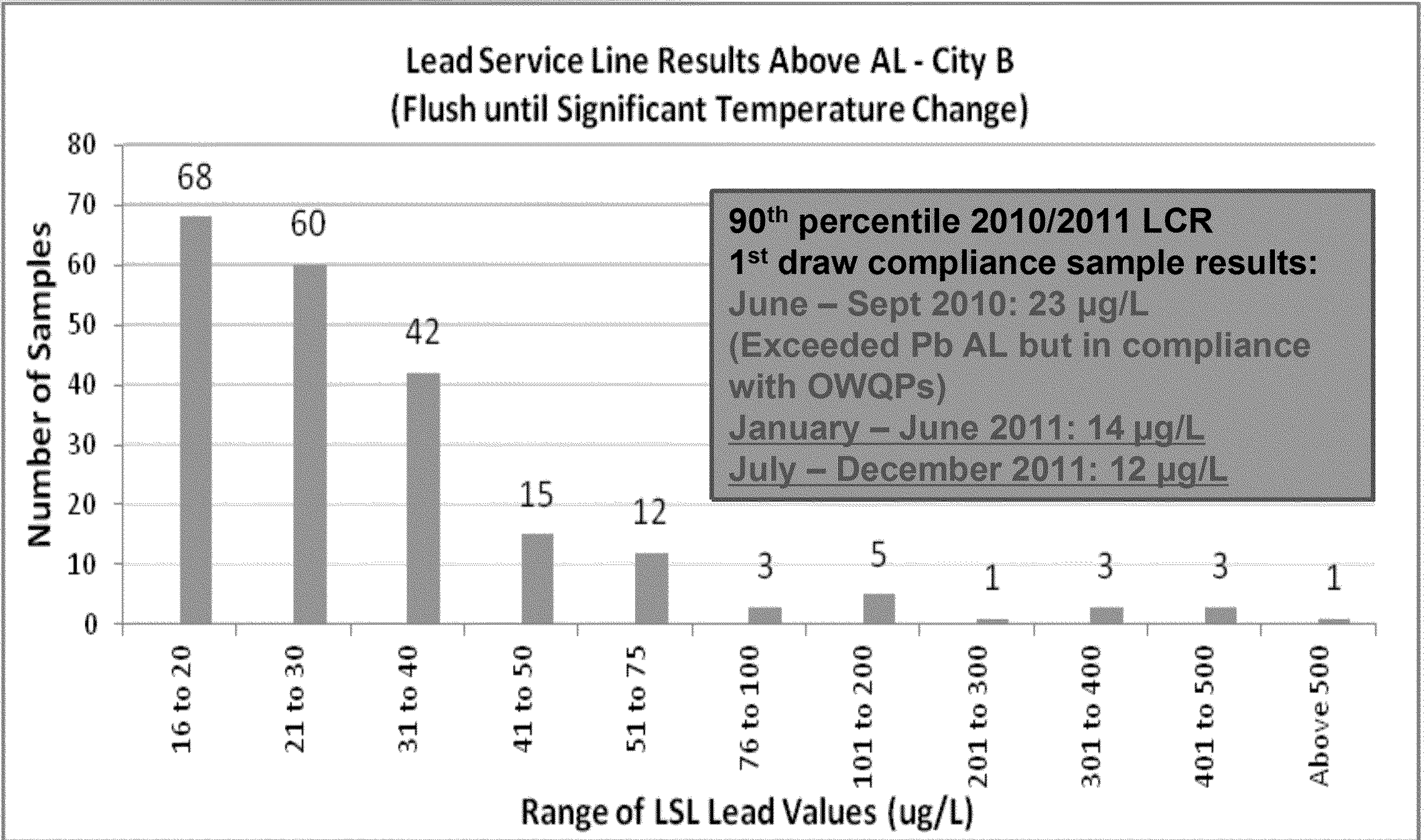
Optimal Water Quality Parameters Are Not Controlling Pb/Cu Levels

- A PWS is in compliance with requirement to minimize Pb/Cu levels if they meet the OWQPs designated by the State.
- Since original LCR was promulgated:
  - Over 6,000 lead action level exceedances for CWSs in SDWIS/FED
  - Many more copper action level exceedances at CWSs and many more lead and copper action level exceedances at NTNCWSs
  - Most systems are in compliance with OWQPs.
    - Only 172 OWQP violations over same timeframe indicates that LCR's OWQP compliance framework is not effectively controlling lead levels.

Comparison of 90th Percentiles



Comparing 1st Draw to LSL Samples Using LCR Sample Protocols

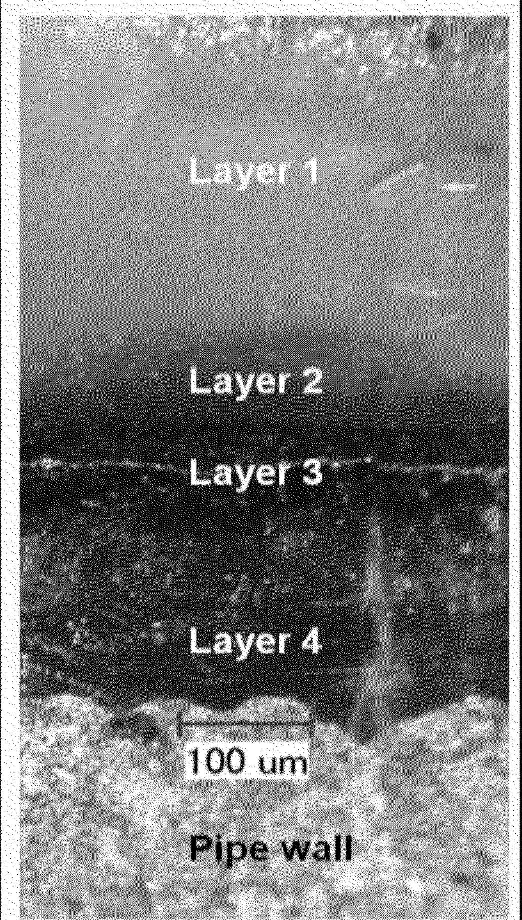


<u>2011 LSL Sampling Results (1,975 Sites Sampled)</u>
213 results (11%) above the lead AL, ranging from 16 µg/L to 580 µg/L.
85 results (4.3%) above twice the AL.

- **90th Percentile using all 1,975 LSL sample results: 16 µg/L**
- **No LSLs were required to be replaced (7 percent of LSLs tested under AL)**

Lead Service Line Scales

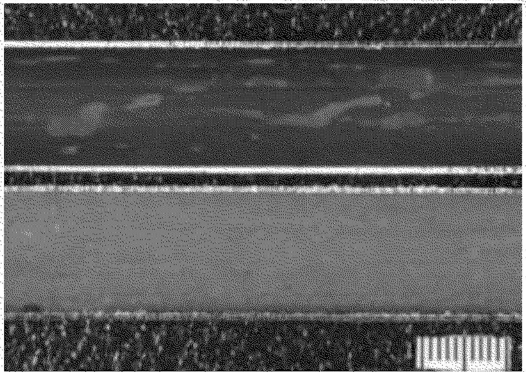
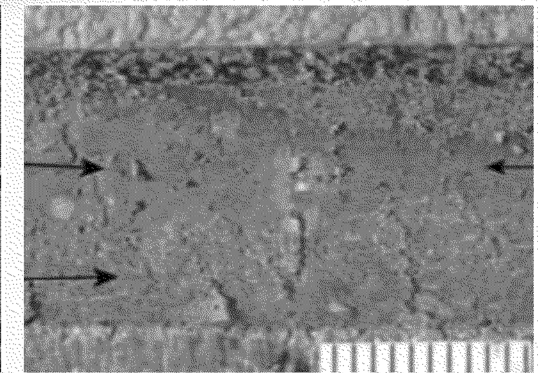
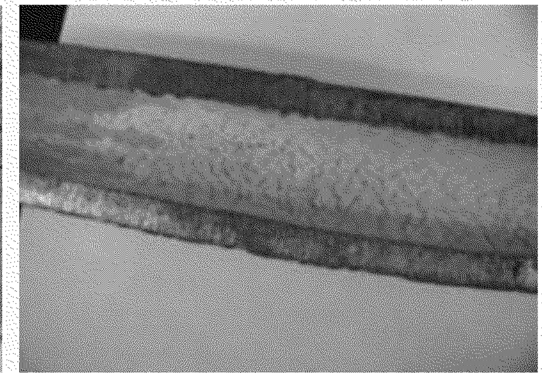
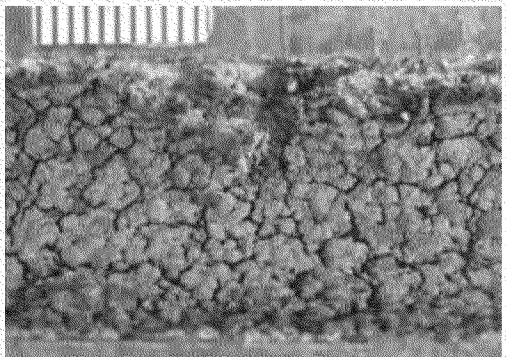
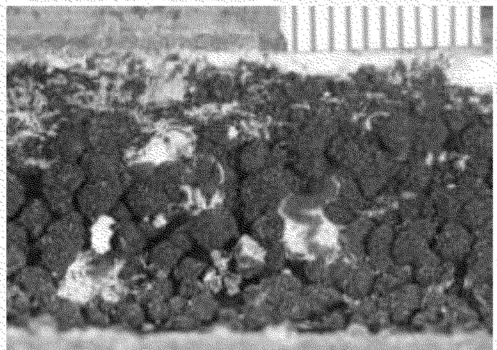
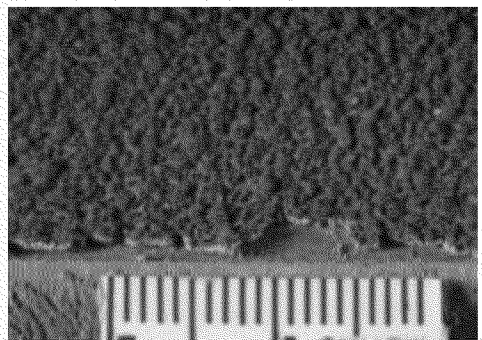
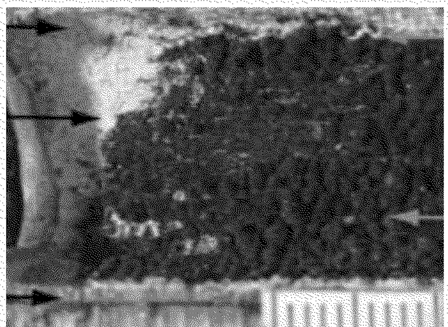
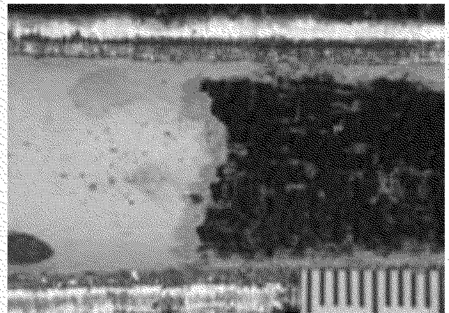
Lead Service Line (LSL) Scales
The composition, stability and solubility of LSL scales can and do vary considerably. It's important to know what is happening inside the LSLs: Unstable scales can result in high particulate release. Studies can inform, and common scientific principles can be used for treatment, but all systems are different, so CCT may not be working according to theory or as anticipated in a given system.



Magnified Scales View: Separated into layers by color and texture.

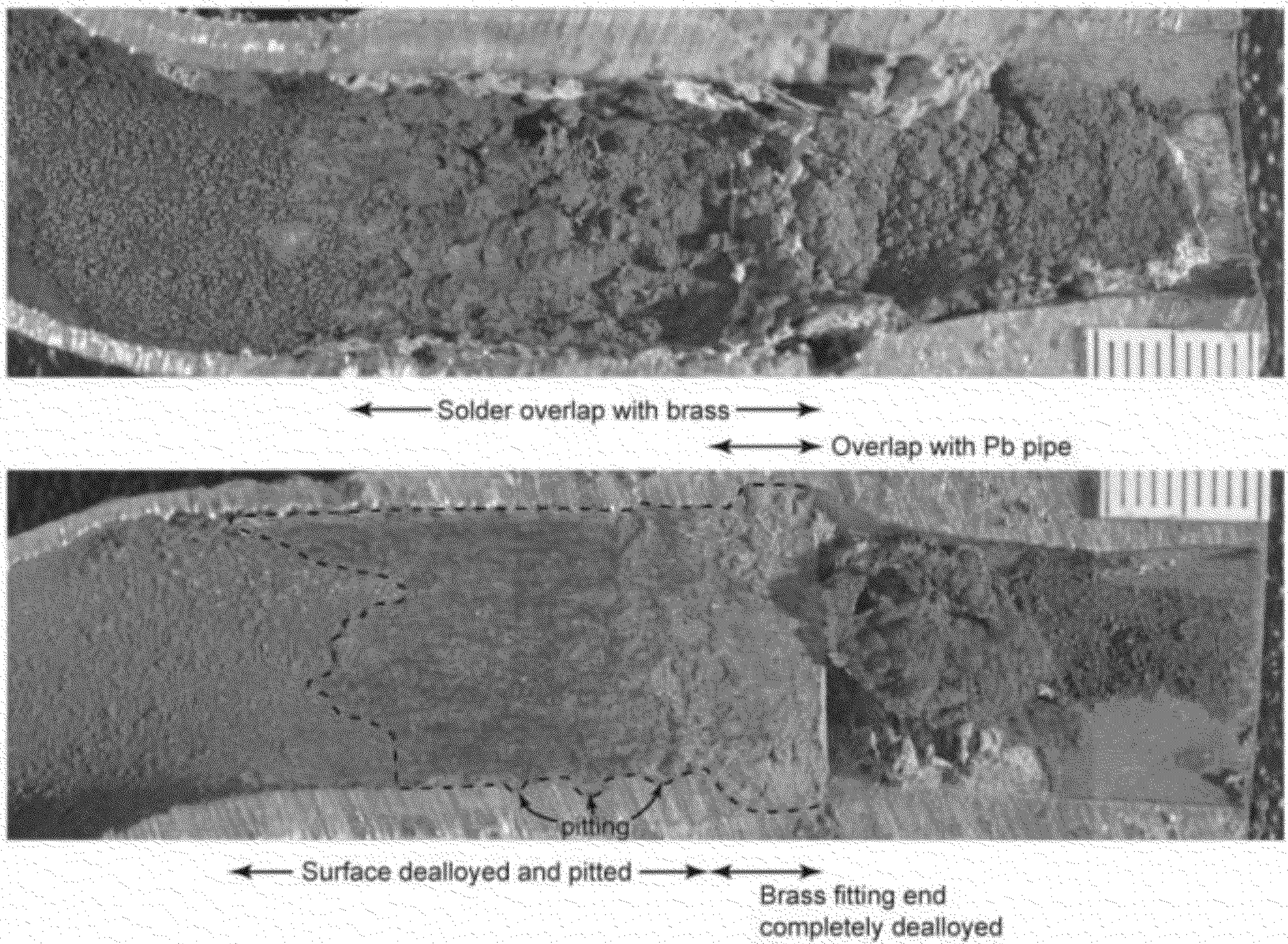
Photo: USEPA-ORD

Lead Service Line Scales

Photos: USEPA-ORD

USEPA-ORD Study on Galvanic Corrosion Evidence



Connections between lead pipe and brass or copper in *some* water systems show boundaries where scale mineral transitions reflect pH conditions much lower than bulk water, consistent with expected impacts of CSMR or other factors increasing galvanic corrosion

Photos: USEPA-ORD

Summary

Is the Water Safe to Drink?

- Based on the health effects studies as well as data and studies in systems with LSLs, the answer is very likely 'no' for most homes with LSLs.
- **Physical LSL disturbances happen daily**
  - Water main repair/replacement; meter and shut-off valve repair, installation & replacement
  - Number of Partial LSLR from infrastructure work far exceeds LCR-required LSLR
- **Maintaining optimal treatment is important, but does not address all risk factors**
  - Homes with low water use; LSL Disturbances; Galvanic corrosion from partial LSLR; Re-occupied homes that were unoccupied for extended periods of time.

Is the Water Safe to Drink?

- **Water quality changes**
  - Can affect Pb levels system-wide or in specific areas
  - Water main material/condition can affect pH/Pb levels in some areas
- Scale/sediment released from LSL disturbances can be dangerous and should be flushed thoroughly out of home plumbing.
- Residents should be reminded that aerators should be cleaned regularly
- **Water usage varies and can change**
  - Varies from site to site and usage at any site can go from high to low, low to high, stay high or stay low.
  - Homes become vacant and are subsequently re-occupied

Additional Information

For more information on Chicago Lead Sampling Study:
http://www.epa.gov/Region5/water/chicagoserviceline/index.html

- Chicago Lead in Drinking Water Study (download)
- Advice for Residents
- How do I know if I have a LSL
- What do LSLs look like
- Cleaning aerators
- Flushing instructions
- Collecting water samples

Questions on LSL scales and analyses:

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(513) 569-7412
schock.michael@epa.gov

Related Journal Article:

Del Toral, M. A., Porter, A., & Schock, M. R. (2013). Detection and Evaluation of Lead Release from Service Lines: A Field Study. *Environmental Science and Technology, 47(16),* 9300-9307. doi:10.1021/es4003636

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Questions

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Water Main Replacement Work
A Field Example

July/August 2012

Miguel A. Del Toral

Note: Construction practices can vary significantly, and some techniques used in this example may or may not be used by other companies.

A trench is dug along the curb for the new water main. After digging the trench the new water main is lowered in place.

Once the new main is placed, it is connected (being done here) and the trench is buried with gravel temporarily.

After they have installed the new main along the entire block, the water in the new main is shock-chlorinated (using concentrated chlorine). Once the bacteriological tests come back clean, they start excavating again to disconnect the lead service lines from the existing main and connecting them to the new main. The old main is next to the new one so they have to break up more street to get to service connections on the opposite side of the old water main which connect across the street.

Once they dig out the gravel and uncover the new main again, they install a tap fitting using this machine, which drills a threaded hole into the new main, and then a threaded fitting (next pic) is installed using the same machine.

This is what the new fittings (main taps) look like.

They then excavate around the existing lead service line (shown by red arrow) using a shovel.

Next, because they can't get to the service shut-off valve on the old water main, two 2-lb hammers are used to pound the existing lead service line shut. Some utilities excavate to the old main and shut the water off by turning the shut-off valve.

Once the lead pipe has been collapsed shut, they have to cut the lead pipe to be able to attach it to the new water main (nextpic)

The lead service line is cut with snips. They cut partially, rotate it, cut more, rotate, etc., until they cut through it.

In this case the lead pipe was not completely collapsed, so water sprays from the pipe which is still connected to the old water main.

The lead pipe is pounded more to stop the water flow. Since the part of the lead pipe being pounded is connected to the old main, it is just pounded shut and left in place.

This is the remaining portion of the lead service line to the home, so they will attach this to the new main. Although the cut is clean, there is significant bending of the lead pipe to bring the edge out and also when connecting to the copper pipe. Lead is more flexible than copper, so they typically bend the lead pipe to make the connection.

This is a bronze compression fitting being put on the LSL end.

Segments of copper pipe are cut, and a coupling is slipped over the end of the pipe. A metal flaring tool is inserted to flare the end of the copper tube (next pic) so it does not slip out of the coupling.

This is what the flared end of the copper tube looks like.

The copper pipe is ready to connect. The flaring tool is shown above. The other end of the copper tube will be flared in the trench.

The valve on the new main is opened slightly to allow the water to run to clear any debris.

A thread sealer is applied while the water runs.

The copper pipe is too long to make the connection to the lead pipe and must be cut.

The copper pipe is cut using a rotary cutter.

The final cut copper pipe.

The bronze connector is slid onto the copper pipe and the end of the copper pipe is flared.

The lead and copper pipe are connected. In this case a dielectric fitting was not used, potentially increasing the risk of galvanic corrosion of the lead pipe.

Once the pipes are joined, the valve is opened to check for leaks.

The new connection to the main was not sufficiently tightened, so water sprays out once the valve is opened.

Tightening the connection stops the leak.

Once all is tightened and there are no leaks, the work here is done.

View of final connection from the sidewalk level

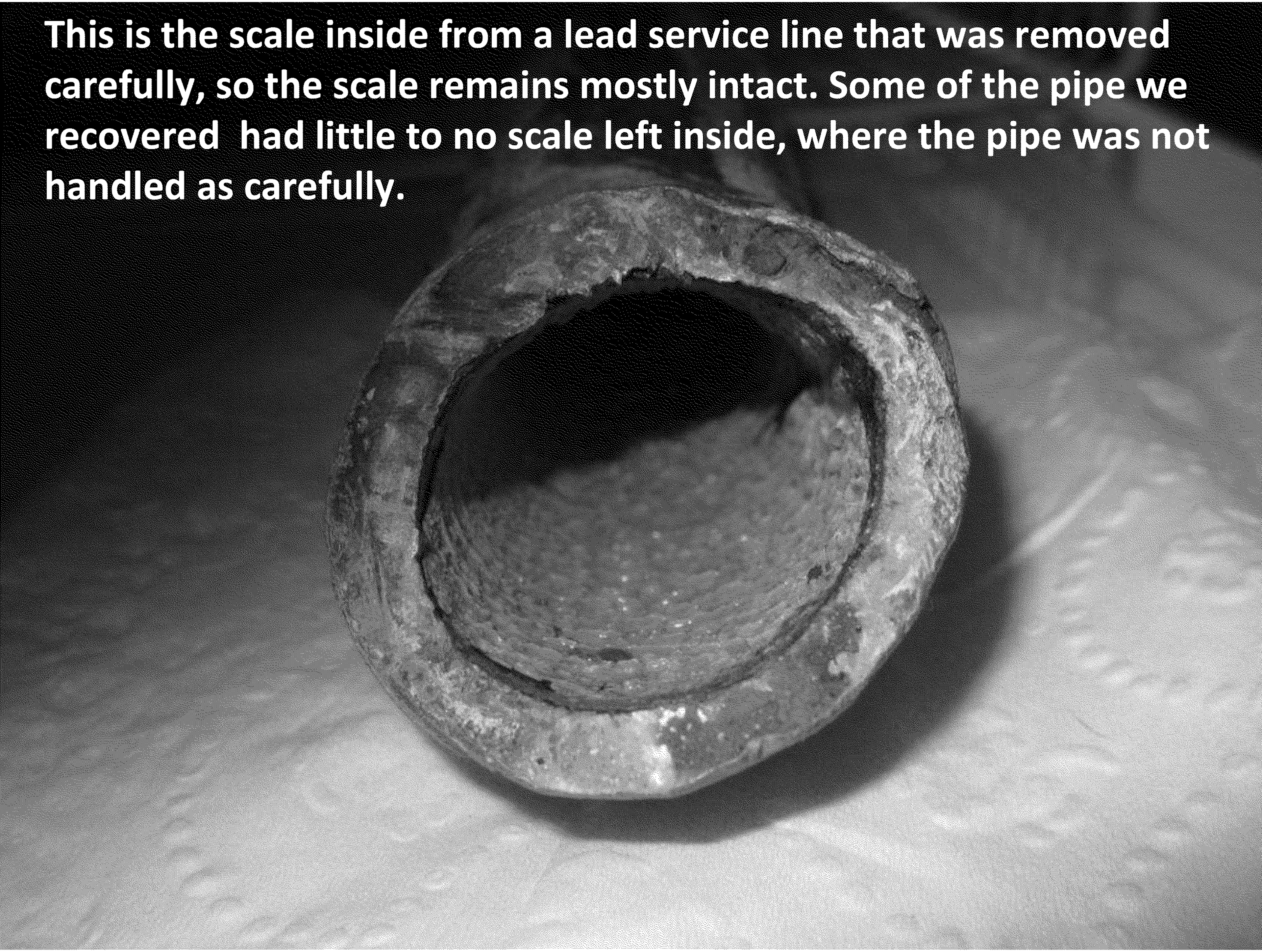
Once the connection is made and there are no leaks, the trench is filled with gravel

The previous pictures were a connection to the near side home. This copper connection is longer, going across the trench since the home is on the other side of the street.

The excavation work in the street caused a leak in the existing lead service line, so a lateral trench was dug along the lead line to reach the leak. An additional length of the lead line was removed and replaced with copper pipe and a new shut-off valve was installed.

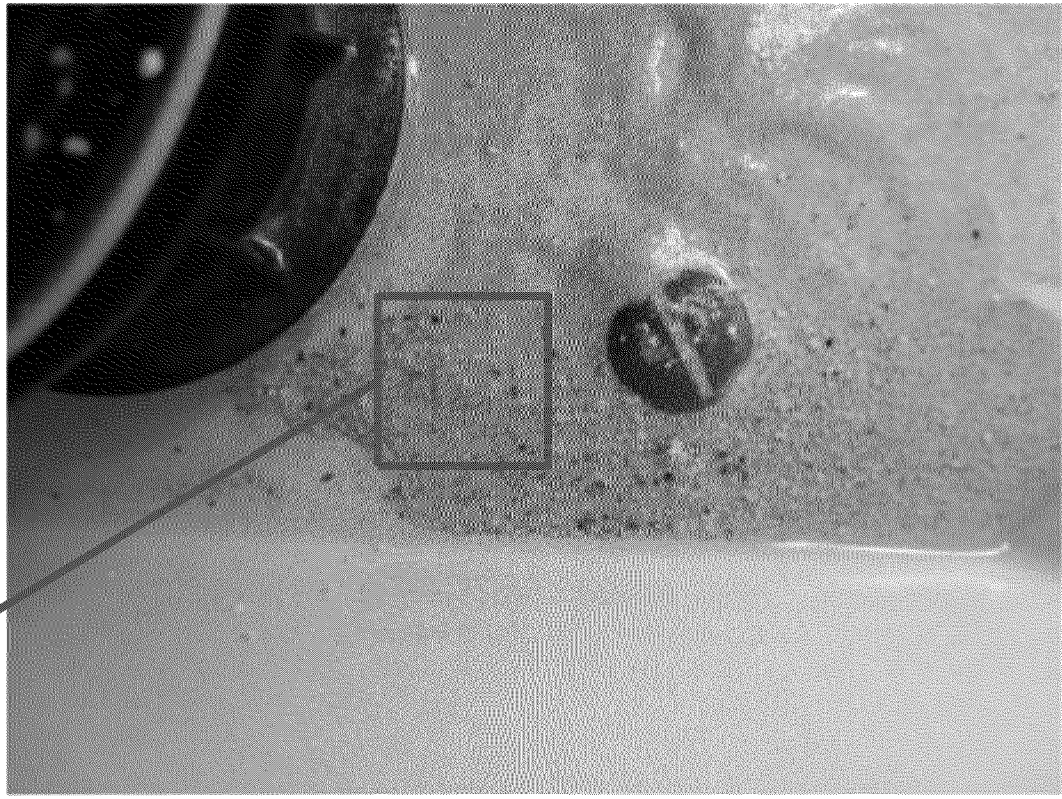
In this picture the lead line was replaced with copper pipe from the main to the edge of the sidewalk at the right.

This is the same location as the last slide. Another (shorter) segment of copper pipe is connected to the lead line serving the home across the street.

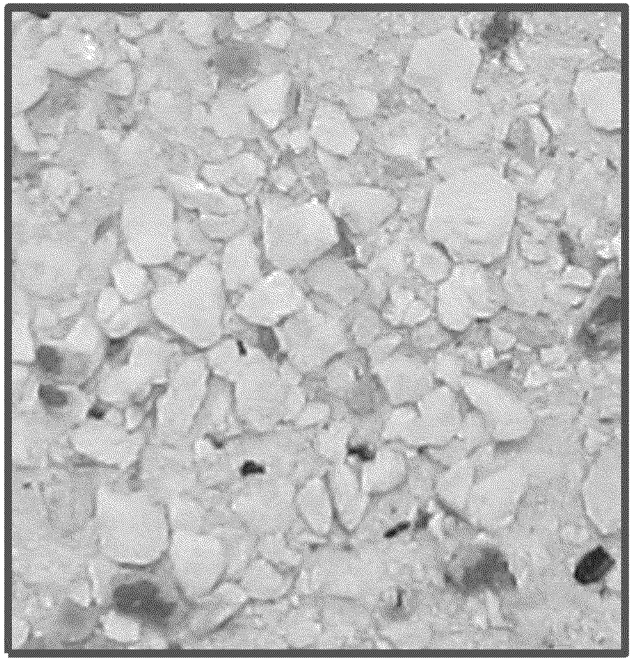

This is the scale inside from a lead service line that was removed carefully, so the scale remains mostly intact. Some of the pipe we recovered had little to no scale left inside, where the pipe was not handled as carefully.

This section of lead pipe which was extracted has only residual scale left inside.

The scale and sediment released following the physical disturbance and partial replacement of a lead service line was collected and the lead levels in the scale and sediment were measured.



The scale and sediment contained extremely high lead concentrations.



Sediment/Scale → Primarily Aluminum, Phosphorous & Calcium

- 330,000 ug/L Pb in particulate sample
- 125,000 ug/L Pb in suspended sample

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Detection and Evaluation of Elevated Lead Release from Service Lines: A Field Study

ISAWWA

February 3, 2014

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Disclaimer: Any opinions expressed in this paper are those of the authors and do not necessarily reflect the official positions and policies of the EPA.

Outline

- **Background Information**
  - Overview of LCR Sampling Requirements
  - Background on Study
  - Purpose of Study
- **Study Findings**
  - LCR sampling protocol significantly underestimated peak lead (Pb) levels and probable mass of released Pb
  - Lead concentrations varied significantly within Lead Service Lines (LSLs).
  - The majority of high lead results occurred at sites with LSL disturbances, with low water usage potentially playing a role.
  - EPA and others' flushing recommendations can lead to higher lead exposure
  - Lead levels were higher in warmer water temperature months
- **Additional References and Resources**

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Background Information
LCR Sampling Requirements

- **Variability of Pb levels in drinking water**
  - Pb can vary depending on site selection, sampling protocol, different corrosion mechanisms, homes with and without lead service lines, lead service line disturbances, water use, water chemistry/quality

EPA LCR (1991): "There is a high degree of variability in lead levels between and within systems as well as between individual taps. As a result, a sufficient number of samples is required in order to be confident that the measured lead levels are accurately assessed. This contrasts with other contaminants where variability is relatively small, and large numbers of samples are not required."

EPA LCR (1991): "EPA has sought to increase the degree to which the sampling will "catch" high levels in the system by requiring sampling at high-risk sites. The number of samples required by the final rule will, in EPAs judgement, sufficiently account for variability at taps while at the same time being reasonable for systems to implement."

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Background Information
LCR Sampling Requirements

- LCR Site Selection and Sampling Protocol
  - Intent is to use worst-case conditions (site selection and sampling protocols) to find the highest lead
  - In 1991, the first-draw sample was intended to capture Pb from leaded solder, leaded brass and lead pipes/service lines
- Worst-Case Sampling Conditions
  - If worst-case conditions were not used, the number of samples required to characterize lead levels would have to increase

EPA LCR (1991): "Targeting monitoring to worst-case conditions will help systems and States evaluate the reductions in contaminant levels achieved through treatment and determine when "optimal" treatment is being maintained to the degree most protective of public health."

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Background Information
LCR Sampling Requirements

LCR compliance is based on a '90th percentile value'.

No. of samples based on population

90th Percentile – Math Refresher:

- For a set of values, the 90th percentile is the number where 90% of the values are lower.
- Example: For a set of 10 values, order them from high to low; 90% percentile = the ninth value from the bottom.

18.3 µg/L
14.4 µg/L
12.3 µg/L
12.1 µg/L
9.5 µg/L
9.2 µg/L
8.7 µg/L
3.4 µg/L
3.1 µg/L

A PWS that exceeds the Pb AL based on their 90th percentile value must undertake the actions specified in the LCR.

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Explaining The Risk
What is a Pb 'Action Level'?

- The action level is simply that
  - EPA's lead action level is a threshold value which requires public water systems to ***take action*** to reduce consumers lead exposure if lead levels exceed the lead 'action level' of 15 ppb.
    - Set at 15ug/L in 1991 based on EPA's understanding of the existing treatment capabilities and treatment costs at that time (i.e., achievable level)
- The Pb action level is NOT health-based
  - It's not a threshold level that separates safe and unsafe Pb levels
  - Based on EPA and CDC Risk Assessments:
    - There is no safe level of exposure to lead.
    - Infants, children and pregnant women should avoid all exposure to lead.

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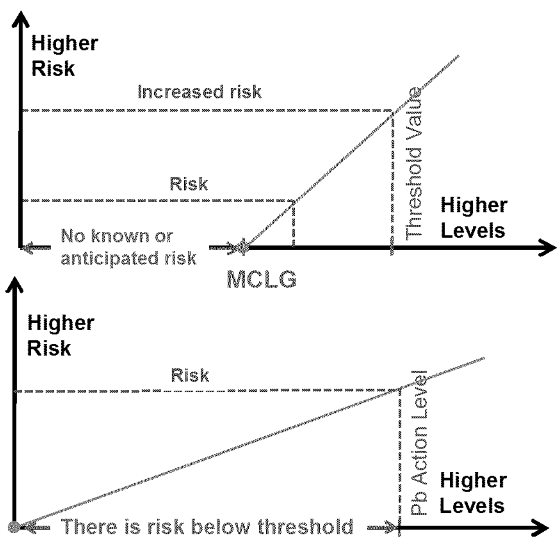
Explaining The Risk (Simplified Linear Risk Example)



When MCLG = specified value (<u>not zero</u>) = no known or anticipated adverse health effects occur below that value.

The Pb action level is above the health-based MCLG of zero, and so there is a risk from lead exposure below EPA's Pb action level.

Pb MCLG = 0 = No level without known or anticipated adverse health effects

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On to the study…

Background Information
Purpose of Study

- **Purpose of Study**
  - To evaluate the method used by public water systems to collect compliance samples for lead in drinking water.
- **Although lead contributions from plumbing have changed, the LCR sampling protocol is prescriptive and has never been updated.**
  - Leaded solder contribution has gone down in 20+ years since use was banned
  - Allowable lead in brass and other plumbing fixtures has been significantly reduced in Lead in Drinking Water Reduction Act, effective in Jan 2014.
  - Lead service lines will continue to be the largest source of lead in drinking water

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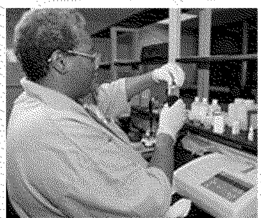
Background Information
Study Roles and Responsibilities

EPA:
- solicited volunteers
- analyzed samples
- estimated LSL lengths



Chicago Department of Water Management:
- water quality data
- Water main, service line materials data
- water usage data
- work reports / data on disturbances to LSLs

Volunteers:
- collected samples
- provided plumbing info
- info on LSL disturbances

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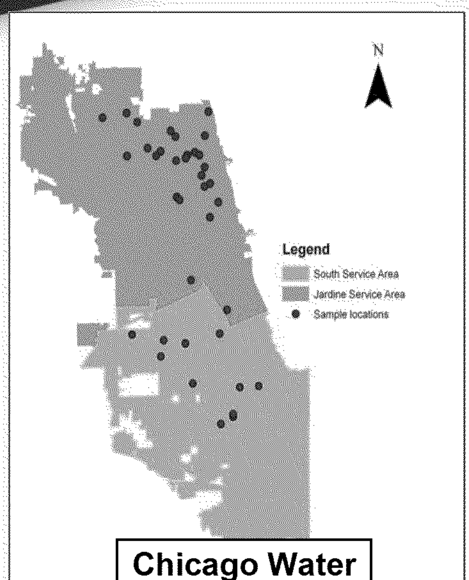
Background Information
Study Basics

- **Homes were built between 1890 and 1960**
  - 23 homes are served by Jardine plant
  - 9 homes are served by South plant
- **Estimated lengths of LSLs ranged from 43 ft to 159 ft (13.1 to 48.5 m)**
  - Information was unavailable for 2 sites
  - Some lead service lines extended beyond the front wall further into the home



Chicago Water Service Areas

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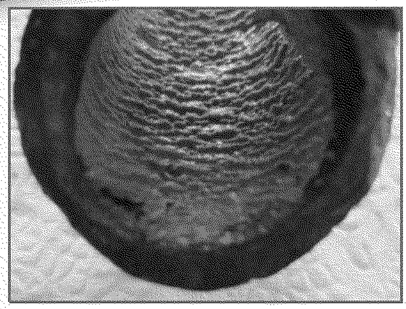
Background Information
Chicago Department of Water Mgmt

- LCR Compliance Status?
  - ✓ Based on first-draw samples, per LCR requirement.
  - ✓ Consistently met LCR Pb action level since 1993.
- Corrosion control treatment? Blended phosphate addition for last 19 years at two conventional treatment plants
- Chemical Additions? Chlorine; Aluminum Sulfate or Alum and Polymer; Activated Carbon; Fluoride



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Background Information
Chicago Department of Water Mgmt

Water Quality (2011)				
Parameter	Outlets		Distribution	
	Min	Max	Min	Max
Temp (C)	4	24	5	23
Turbidity (NTU)	0.1	0.2	0.1	0.4
pH	7.5	7.8	7.7	7.8
Cl_2 Residual (mg/L)	1.0	1.2	0.7	0.9
Total Alkalinity (mg/L as $CaCO_3$)	103	108	98	108
Chloride (Cl, mg/L)	16	20	17	20
Sulfate (mg/L)	29	31	29	30
Ca (mg/L)	34	39	34	39
PO_4 (mg/L)	0.4	0.6	0.5	0.5
Total PO_4 (mg/L)	0.8	1.1	0.8	1.2
Al (µg/L)	34	126	29	113
Fe (µg/L)	<5	<5	<5	34
Mn (µg/L)	<3	<3	<3	<3

Chicago LCR Compliance Data

City of Chicago (1992 – 2010) 90th Percentile Lead Values (µg/L)			
Monitoring Period Begin	Monitoring Period End	No. of Samples	90th %ile Value
1/1/2008	12/31/2010	50	6
1/1/2005	12/31/2007	50	6
1/1/2002	12/31/2004	50	4
1/1/1999	12/31/2001	50	7
1/1/1999	12/31/1999	50	8
1/1/1998	12/31/1998	53	14
7/1/1997	12/31/1997	100	11
1/1/1997	6/30/1997	100	10
1/1/1993	6/30/1993	100	13
7/1/1992	12/31/1992	120	20
1/1/1992	6/30/1992	100	10

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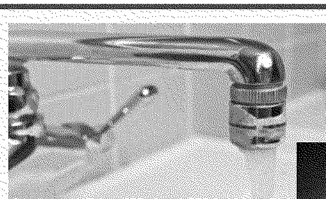
Background Information
Study Sampling

All samples → Volume = 1 liter; Stagnation time >= 6 hours

Three rounds of monitoring:

1) Mar/Apr 2011
   - ✓ first-draw
   - ✓ flushed: 45 sec
2) June 2011
   - ✓ 12 sequential
3) Sept/Oct 2011
   - ✓ 11+ sequential
   - ✓ first-draw
   - ✓ flushed: 3, 5, 7 minute



- "First-draw" included normal household use (NHU) or pre-flushing (PF) prior to a minimum 6 hour stagnation time

First-Draw :: 1st Sequential :: LCR-Type Compliance Samples

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Background Information
Study Sampling

- **First-draw samples**
  - Pre-flushed (PF) First-Draw Samples
    - Volunteers were instructed to run the water for 5 minutes before beginning the minimum 6 hour stagnation period before sampling.
  - Normal Household Use (NHU) First-Draw Samples
    - Volunteers were instructed to use water as it is normally used in the household, but allow a minimum 6 hour stagnation period before sampling. Volunteers were not instructed to run the water for 5 minutes the night before.
- **Flushed sample (45 second, 3 min, 5 min, 7 min, 10 min)**
    - Run the water for the specified amount of time and then collect the sample.
- **Stagnation times (all samples)**
  - Most stagnation times were relatively consistent across most sites at between 6 and 8.5 hours
  - All but two sites had stagnation times ranging from 6 hours to 9 hours 10 min

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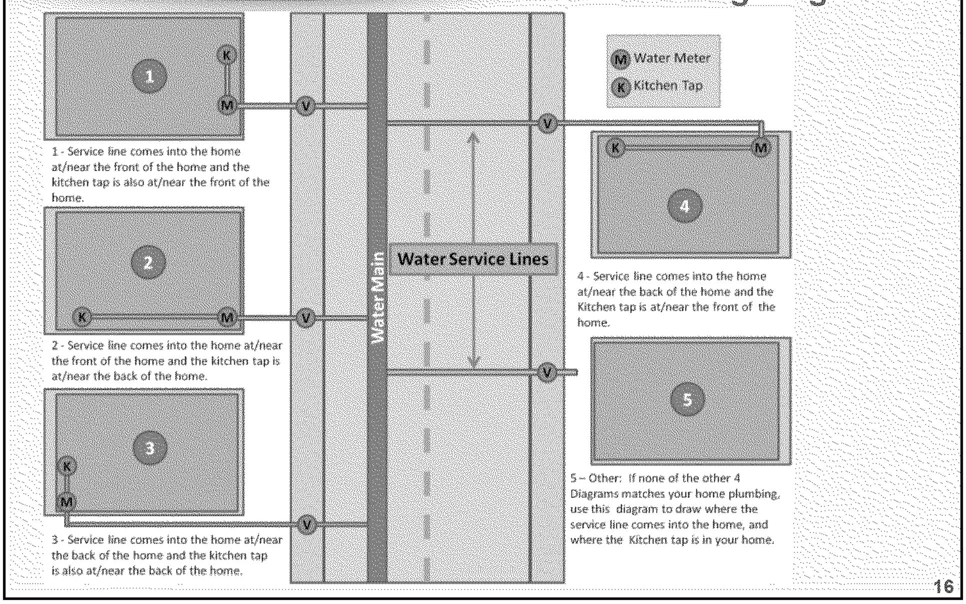
Background Information
Study Sampling

Plumbing Diagrams



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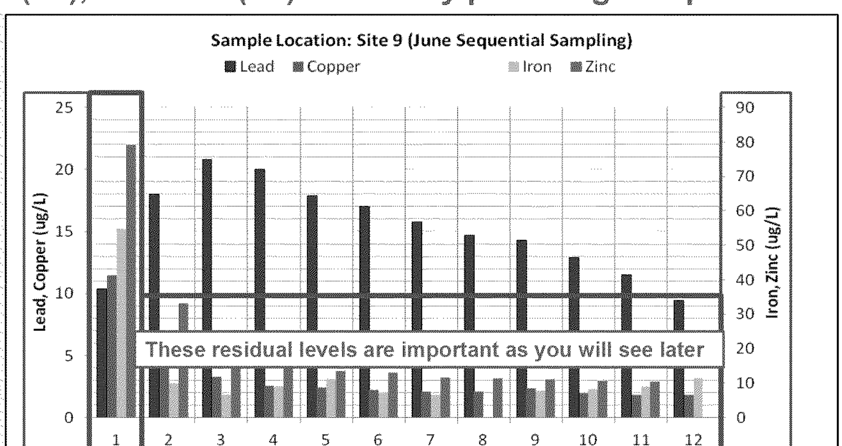
Background Information
Sample Analyses

All samples were analyzed for Lead (Pb), Copper (Cu), Iron (Fe), and Zinc (Zn) to identify plumbing components



Plumbing: 102 feet from water main to meter. From meter: 6.5 ft galvanized iron pipe riser, then 7 ft horizontal run of galvanized iron pipe through crawl space, to kitchen sink. Galvanized iron pipe is 1 inch diameter.

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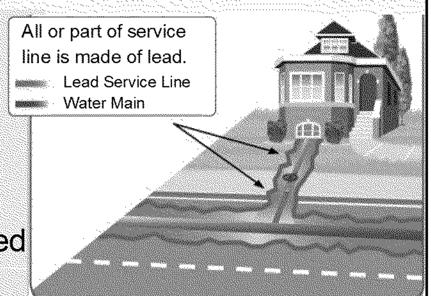
STUDY FINDINGS

Study Findings
Summary of Findings

In Lead Service Line systems, existing Lead and Copper Rule (LCR) sampling protocol significantly underestimated:

- Peak lead (Pb); and
- Probable mass of Pb released



Additional findings:

- Sequential Sample Peaks > First Draw Pb Levels
- High Variability Within and Across Sites
- Pb Higher in Warmer Months
- Disturbed Sites = Highest Pb
  - Disturbances May Dislodge High-Pb Scale/Sediment
- 45-sec Flush Samples > First-Draw Samples

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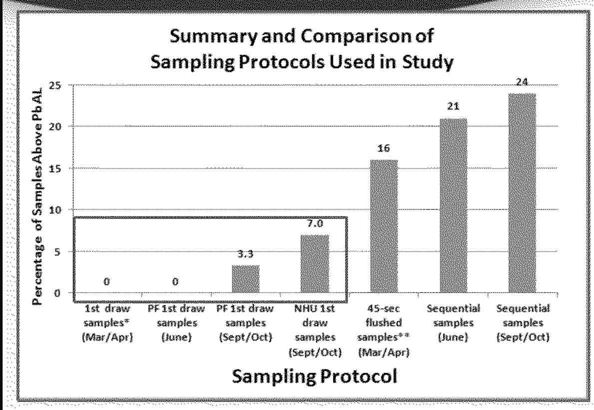
LCR Sampling Protocol Significantly Underestimated Peak Lead (Pb) Levels and Probable Mass of Released Pb

LCR Sampling Underestimates Pb

Missing the Peaks



PF and NHU 1st draw samples each had 0 results above Pb AL in March/April (colder water temperature)

PF 1st draw samples had 1 result above Pb AL in Sept/Oct

NHU 1st draw samples had 2 results above Pb AL in Sept/Oct.

Summary and Comparison of Sampling Protocol Results							
	1st draw samples* (Mar/Apr)	PF 1st draw samples (June)	PF 1st draw samples (Sept/Oct)	NHU 1st draw samples (Sept/Oct)	45-sec flushed samples** (Mar/Apr)	Sequential samples (June)	Sequential samples (Sept/Oct)
No. of Samples	64	28	30	29	64	336	319
No. > AL	0	0	1	2	10	69	75
% > AL	0	0	3.3	7.0	16	21	24

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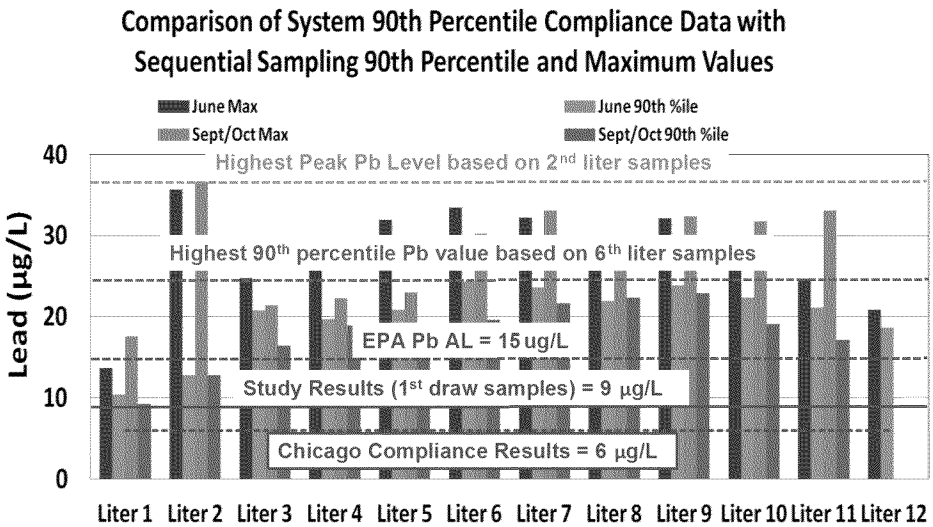
LCR Sampling Underestimates Pb

Missing the Peaks



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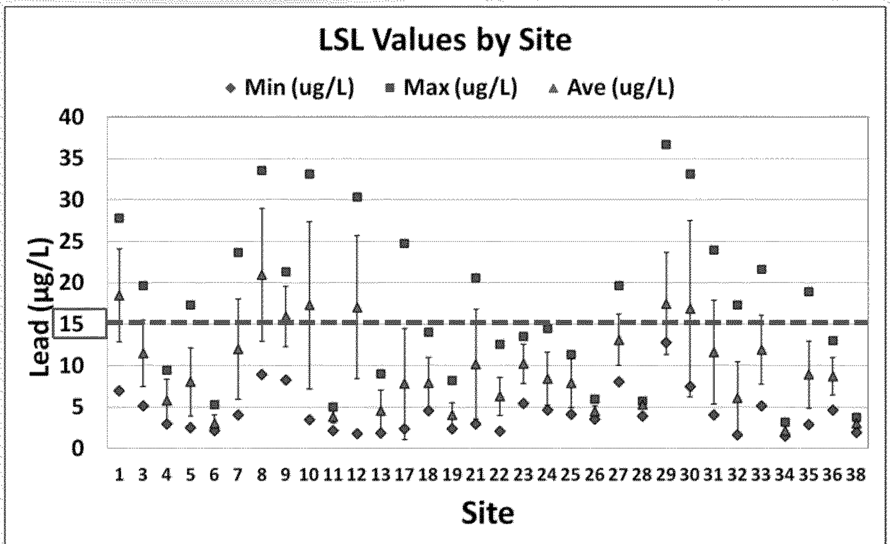
Lead Concentrations Vary Throughout Each Individual LSL and among Different LSLs Across the System.

Pb Levels are Highly Variable (within and across sites)



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LCR Sampling Underestimates Pb
Missing the Peaks

- Why are Pb levels so variable?
  - Lead service lines vary in length
  - Length of internal plumbing before LSL varies significantly and every home's plumbing is different
    - Some LSLs end just inside the front wall
    - Some LSLs continue beyond the front wall
    - Kitchen tap locations vary home by home (front, middle, back of home, same side as meter/opposite side from meter)
  - Corrosion mechanisms can be different
    - Uniform corrosion
    - Galvanic corrosion
    - Particulate Pb release / transport of Pb with Fe/Mn particles into homes
  - LSL disturbances can occur at different points in the LSL
    - Water main repair or replacement or significant street excavation
    - Service shut-off valve or leak repair or replacement
    - Water meter or AMR installation or repair
  - Water use varies

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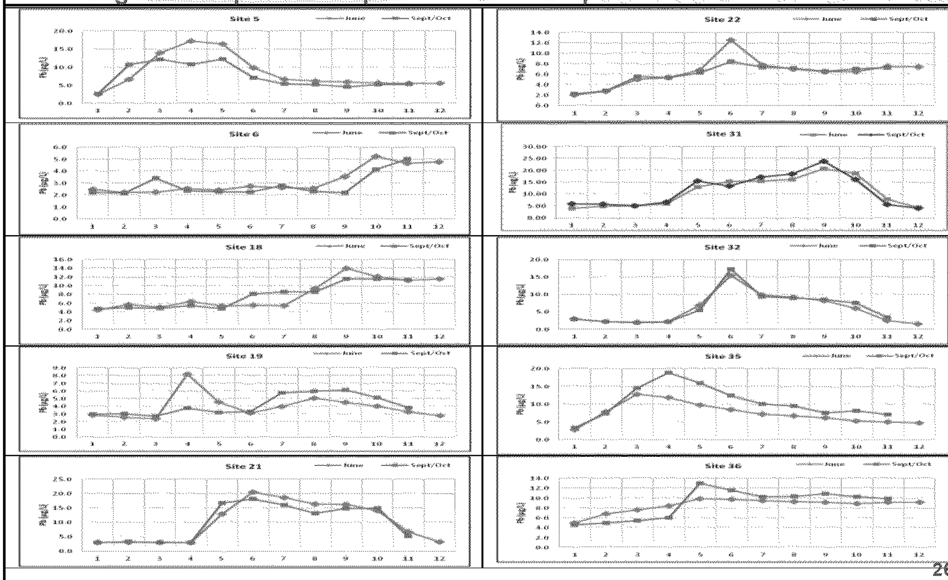
LCR Sampling Underestimates Pb

Missing the Peaks

Using one sample for compliance misses the peak Pb at most or all sites.



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LCR Sampling Underestimates Pb

Missing the Peaks

Using one sample misses peak Pb at most sites

June (28 Sites)												
If this liter is used across all sites	1st liter	2nd liter	3rd liter	4th liter	5th liter	6th liter	7th liter	8th liter	9th liter	10th liter	11th liter	12th liter
No. of sites that miss peak lead value	28	27	26	25	26	22	25	28	24	24	28	26
Percent of sites that miss peak lead value	100%	96%	93%	89%	93%	79%	89%	100%	86%	86%	100%	93%

September / October (30 Sites)											
If this liter is used across all sites	1st liter	2nd liter	3rd liter	4th liter	5th liter	6th liter	7th liter	8th liter	9th liter	10th liter	11th liter
No. of sites that miss peak lead value	30	29	28	27	28	25	24	30	23	28	28
Percent of sites that miss peak lead value	100%	97%	93%	90%	93%	83%	80%	100%	77%	93%	93%

The 1st liter is currently used for LCR compliance sampling (missed the peak lead 100% of the time).

Using a specified single liter to collect compliance samples would miss the peak lead values at between 77% and 100% of the sites.

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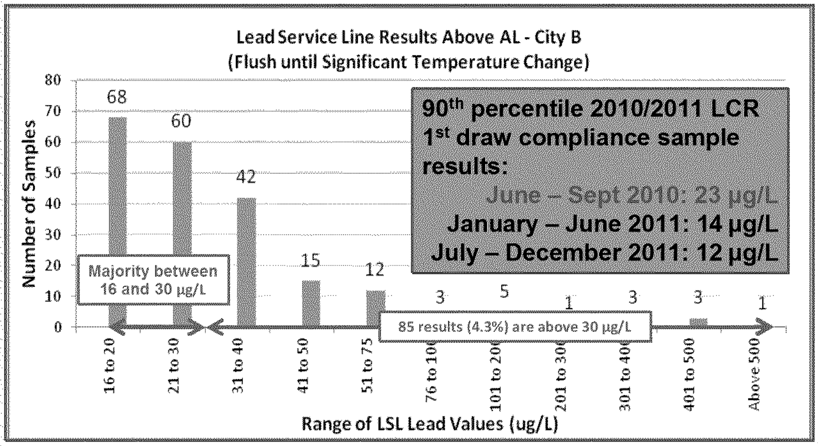
LCR Sampling Underestimates Pb
Missing the Peaks

City B LSL Sample Results (June – Oct 2011)



City B took 1,975 LSL samples in 2011.
A total of 1,762 results (89%) below the lead AL.
213 results (11%) above the lead AL, ranging from 16 µg/L to 580 µg/L.
85 results (4.3%) above twice the AL.

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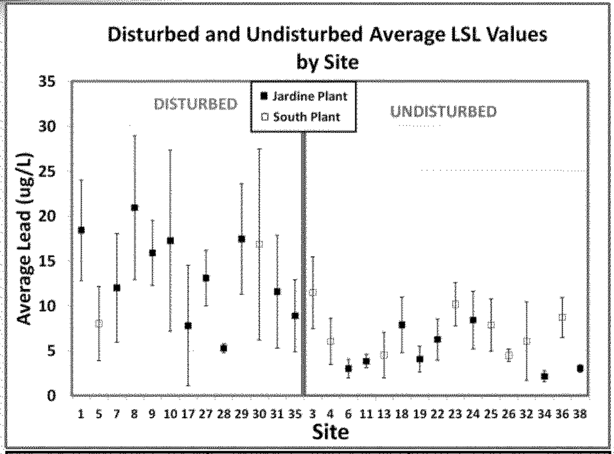
The majority of high lead results occurred at sites with a documented physical disturbance of the LSL

Disturbed LSL Sites had Highest Pb

What is a 'Disturbed LSL Site'?

Disturbed LSL Sites

- Street excavation in front of home (e.g., main replacement)
- External service shut-off valve repair/replacement
- Service line leak repair
- Meter installation or replacement
- Auto-meter-reader (AMR) installation



Indeterminate Sites	Total Samples Collected	No. Samples above Lead AL
12	27	17
21	27	7
33	27	6

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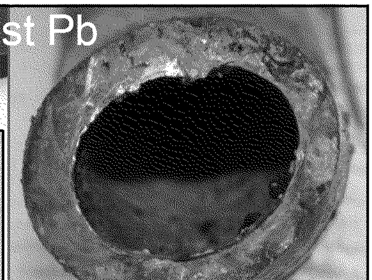
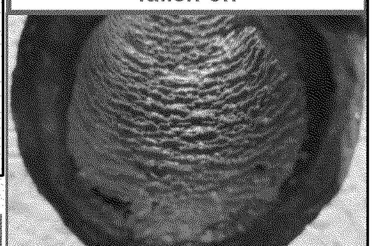
Disturbed LSL Sites had Highest Pb

# of Disturbed Sites	13	**36%** over 15 ug/L
Total Samples Collected	327	
# Samples Above 15 ug/L	117	
# of Undisturbed Sites	16	**2 %** over 15 ug/L
Total Samples Collected (Undisturbed)	372	
# Samples above 15 ug/L	6	

Lead service line disturbances were found to be a common factor for the majority of sites with high lead levels. It is also possible that low water usage may play a role in sites with the highest lead levels.



Disturbance → Scale has fallen off



Disturbance minimized during pipe removal → Intact scale

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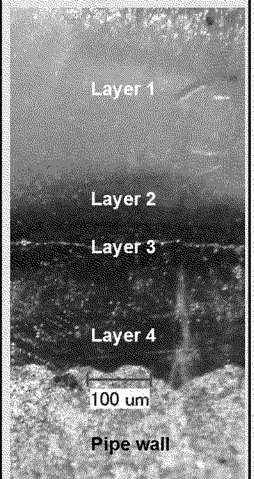
Pipe Scale Analysis:
Overview

General Corrosion Control theory →
Add orthophosphate to form **insoluble** scales on the pipe wall and inhibit Pb release.

How to check?
Characterize corrosion scales on plumbing materials.

Whole Pb Service Line: Cut open to expose corrosion scales.



Magnified Scales View: Separated into layers by color and texture.

2

Pipe Scale Analysis:
Results

	Layer	Al	Ca	Fe	P	Pb	Zn
Pb Service Line Average	1	16	7	1.9	11	14	0
	2	12	4	0.5	6	39	0
	3	4.8	1	0.4	2.1	62	0
	4	0.4	0	0.1	0.2	80	0

*Elements are expressed in weight %.

Conclusions

- No insoluble Pb-phosphate found in any scale layer.
- Layer 1 → blanket-like layer with elevated Al, Ca, and P content.

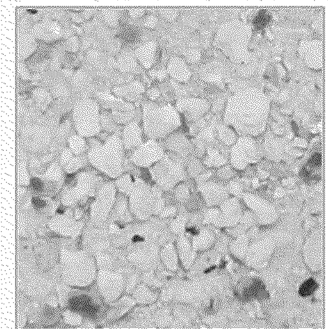
Inhibition of Pb release here does not follow general theory of insoluble scale. Instead, Pb release inhibited by amorphous diffusion barrier (blanket-like layer).

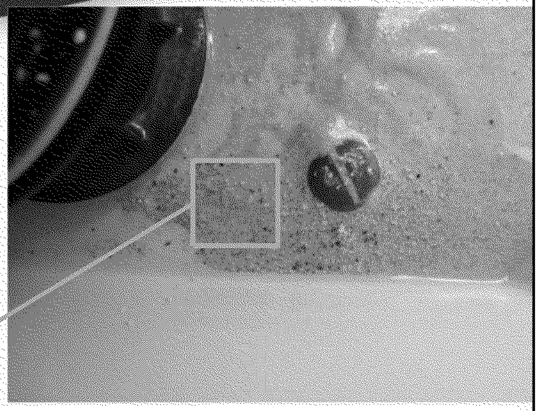
- **Why?** Composition of the Pb pipe barrier layer may be due to reaction of blended phosphate and Al carry-over from coagulation and natural hardness.
- **How does this increase Pb release risk?** Layer 1 is not well-adhered to pipe wall. Layer 1 easily sloughs off when disturbed. Dislodged scale releases particulate Pb. When Layer 1 is knocked off, exposes underlying layers with higher Pb content.

1

Disturbed LSL Sites had Highest Pb

Disturbances Can Dislodge High-Pb Scale/Sediment





Sediment/Scale → Primarily Aluminum, Phosphorous & Calcium

- 330,000 ug/L Pb in particulate sample
- 125,000 ug/L Pb in suspended sample

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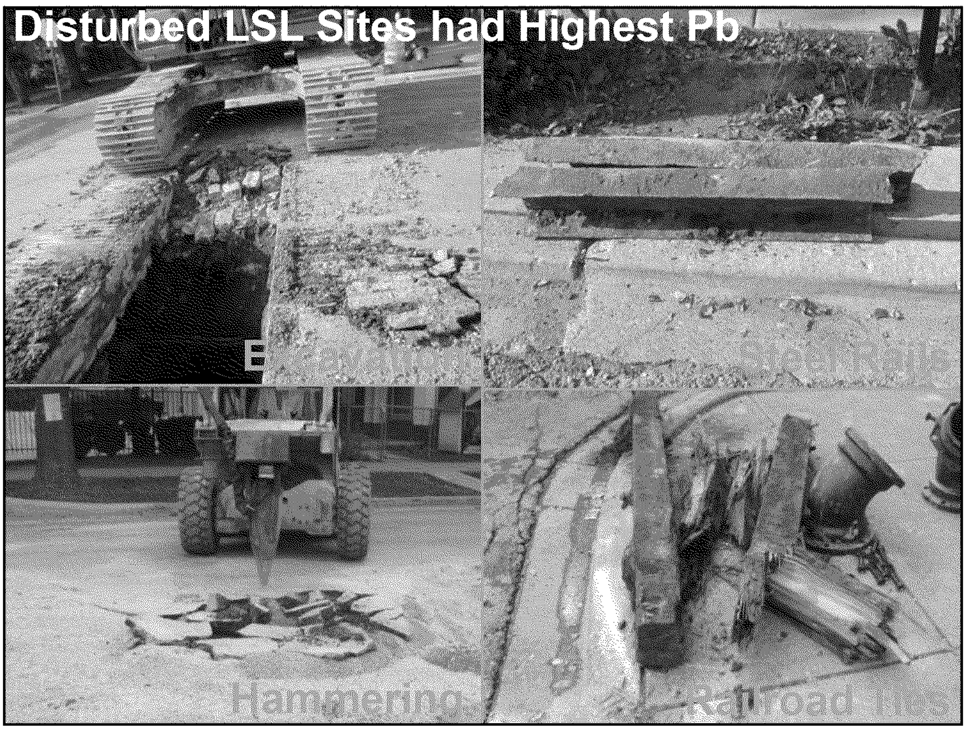
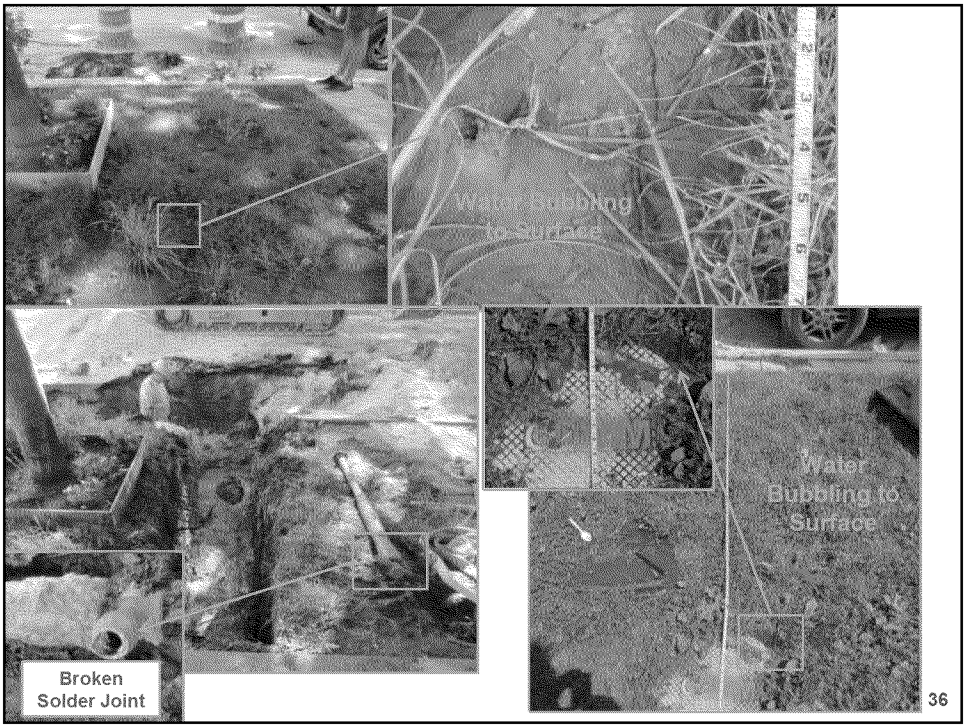
Disturbed LSL Sites had Highest Pb




Water Bubbling to Surface
Broken Solder Joint
Water Bubbling to Surface
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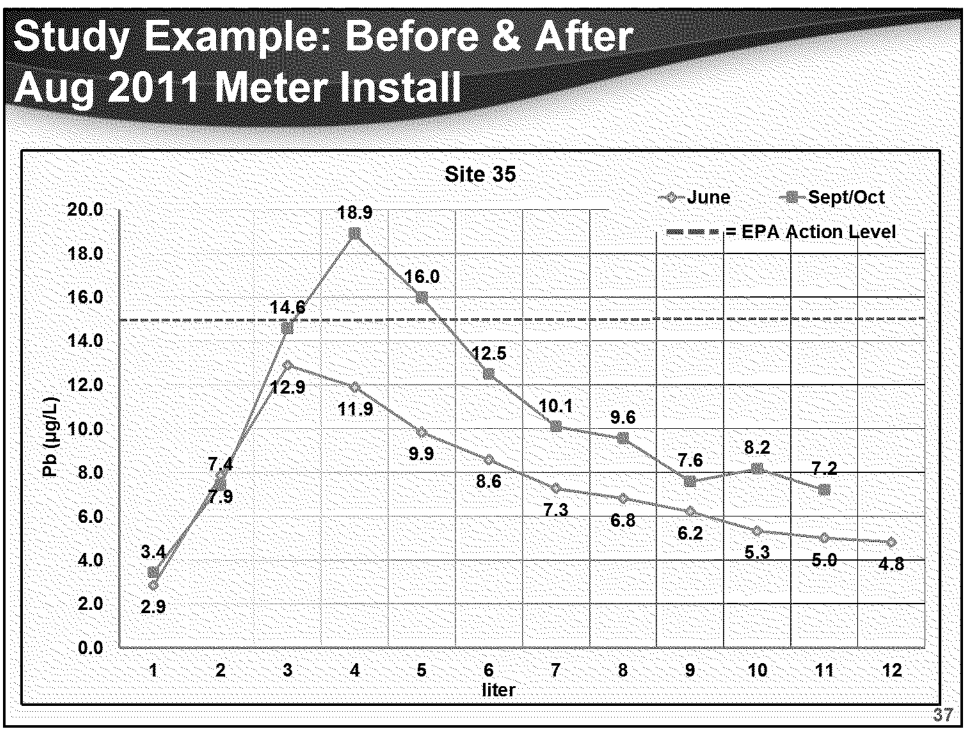
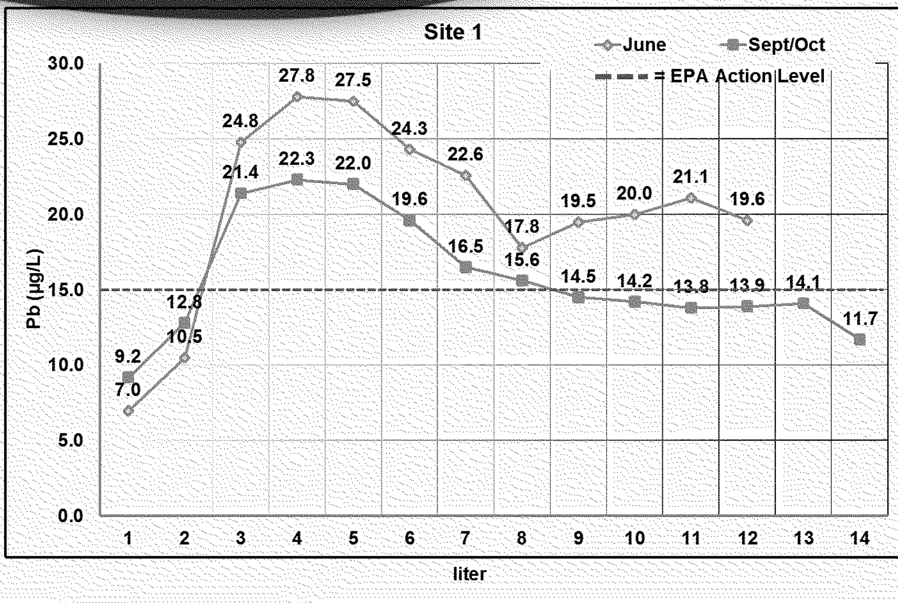

Study Example: Before & After Aug 2011 Meter Install
Site 35
June
Sept/Oct
= EPA Action Level
Pb (µg/L)
liter
18.9
16.0
14.6
12.5
12.9
11.9
10.1
9.6
9.9
8.6
7.4
7.9
7.6
8.2
7.2
7.3
6.8
6.2
5.3
5.0
4.8
3.4
2.9
37

Findings: Low Water Usage May → Higher Pb



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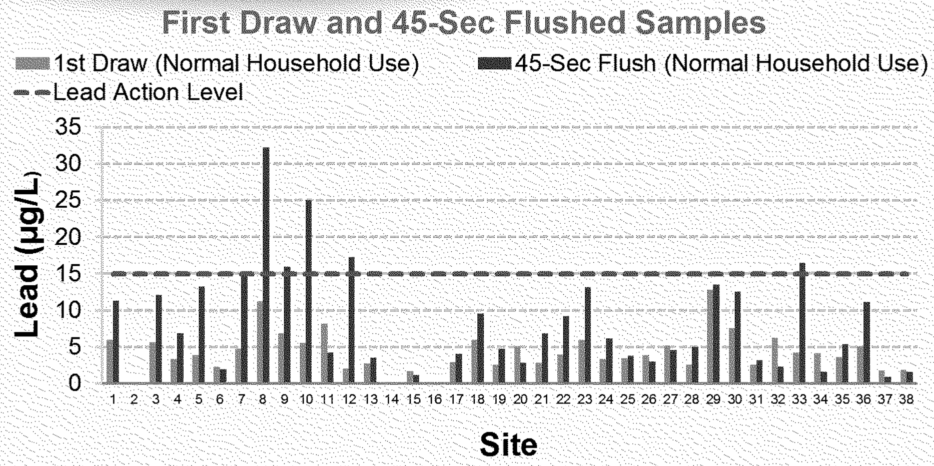
More Appropriate Flushing Guidance Is Needed

Flushing Guidance Takes Consumers to Higher Pb



Results → EPA's '30 to 45 second' flushing guidance can take residents with LSLs to **higher** lead.

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Flushed Sample Summary Table (µg/L)

Site	NHU 45sec	PF 45sec	3min	5min	7min
01	11.3	11.9	6.48	6.56	6.97
03	12.0	6.71	3.78	2.93	
04	6.76	2.56			
05	13.2	14.1			
06	1.90	2.13			
07	15.3	24.9	5.49	5.46	5.32
08	32.2	28.0	8.25	5.54	5.71
09	15.9	17.7	14.3	7.23	
10	25.0	21.6	4.95	4.30	4.09
11	4.13	5.30	1.75	1.69	
12	17.2	5.45	1.78	1.45	1.33
13	3.50	2.94			
17	4.00	3.70	2.88	2.76	2.86
18	9.57	12.4	4.15	3.71	
19	4.69	8.27			
20	2.80	2.54			
21	6.87	13.8			
22	9.19	7.93			

Flushing for 3 to 5 minutes significantly reduced lead levels in homes that had the highest lead levels.

Flushed Sample Summary Table (µg/L)

Site	NHU 45sec	PF 45sec	3min	5min	10min
23	13.1	11.5	5.64	4.54	
24	6.10	4.98	6.38	12.4	
25	3.75	ND			
26	3.02	3.45	5.06	3.23	
27	4.53	3.76	15.0	14.1	
28	4.99	4.70	4.82	3.26	
29	13.5	28.6	11.9	10.9	10.8
30	12.5	6.52	5.80	4.82	
31	3.16	12.3	3.78	3.76	
32	2.29	7.82			
33	16.4	14.0	4.40	4.06	
34	1.51	3.30	1.83	1.75	
35	5.28	10.5	5.53	4.03	
36	11.1	8.76	7.19	5.29	
38	1.60	2.30			

In most cases, flushing longer than 3 minutes did not appreciably reduce lead levels

There remains a 'baseline' level of lead in the drinking water which varies from site to site.

Red text indicates levels above the lead action level.

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Why Pre-flushing before collecting 1st draw samples resulted in the lowest lead levels.

First-draw Sampling Variants

A *NHU first-draw sample* involves using the water as residents normally do before the 6 hour stagnation period and then not using water in the household for at least 6 hours until the first-draw sample is collected.

A *pre-flushed (PF) first-draw sample* involves running water for 5 minutes before the 6 hour stagnation period and then not using water in the household for at least 6 hours until the first-draw sample is collected.

A *5-minute flushed sample* involves running the water for 5 minutes and then immediately collecting the sample (no stagnation period).

	First-Draw		Flushed
	Sept/Oct 2011	Sept/Oct 2011	Sept/Oct 2011
Site	First-Draw NHU	First-Draw PF	5min
Site 1	7.4	9.2	6.6
Site 3	10.0	8.3	2.9
Site 7	5.1	4.0	5.5
Site 8	17.5	9.2	5.5
Site 9	15.3	8.3	7.2
Site 10	5.0	3.5	4.3
Site 11	3.5	3.0	1.7
Site 12	2.3	5.4	1.5
Site 17	2.7	2.7	2.8
Site 18	5.8	4.8	3.7
Site 23	9.2	7.0	4.5
Site 24	7.6	6.6	12.4
Site 26	4.5	4.9	3.2
Site 27	8.3	12.6	14.1
Site 28	4.3	3.9	3.3
Site 29	14.9	17.6	10.9
Site 30	8.4	7.9	4.8
Site 31	4.7	6.0	3.8
Site 33	5.6	5.5	4.1
Site 34	2.1	1.5	1.8
Site 35	5.0	3.4	4.0
Site 36	5.9	4.6	5.3
AVE	7.0	6.4	5.2

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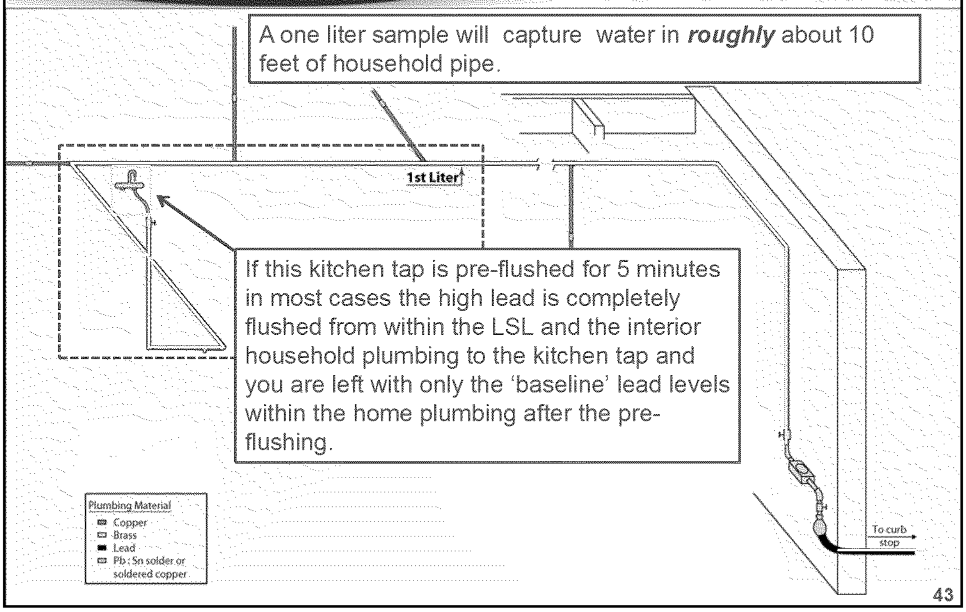
What a pre-flushed 1st Draw Sample Will Capture



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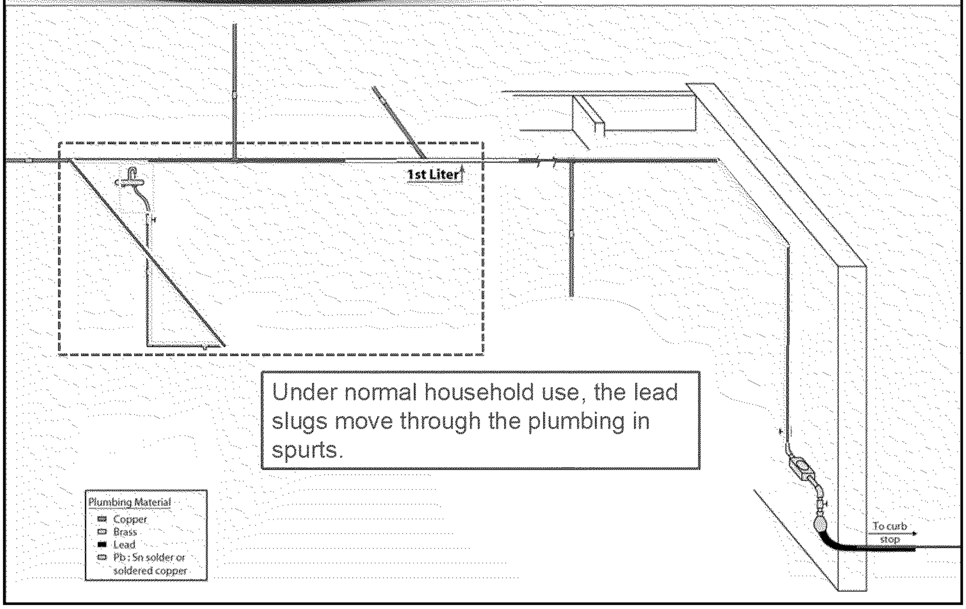
What a NHU First-Draw Sample Can Capture



Under normal household use, the lead slugs move through the plumbing in spurts.

Pre-flushed vs. NHU first-draw samples

A one-liter sample will capture the lead in *roughly* ten feet of pipe from the kitchen tap (varies depending on inner pipe diameter and corrosion inside pipes).

Site 8 – Galv. Fe and Cu pipe: LSL is approximately 54 ft from kitchen tap, so a PF 1st draw sample did not catch LSL water, but a NHU sample will sometimes catch it. Therefore, the NHU result can be significantly higher than the PF result.

Site 9 – Galv. Fe pipe: From Meter/LSL is 13.5 ft from kitchen tap so a PF 1st draw sample did not catch the LSL water, but a NHU sample will sometimes catch it. Therefore, the NHU result can be significantly higher than the PF result.

Site 29 – Short Cu pipe: The LSL comes in through the floor right under the kitchen sink so both the PF and the NHU 1st draw sample caught LSL water.

	First-Draw		Flushed
	Sept/Oct 2011	Sept/Oct 2011	Sept/Oct 2011
Site	First-Draw NHU	First-Draw PF	5min
Site 1	7.4	9.2	6.6
Site 3	10.0	8.3	2.9
Site 7	5.1	4.0	5.5
Site 8	17.5	9.2	5.5
Site 9	15.3	8.3	7.2
Site 10	5.0	3.5	4.3
Site 11	3.5	3.0	1.7
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Site 27	8.3	12.6	14.1
Site 28	4.3	3.9	3.3
Site 29	14.9	17.6	10.9
Site 30	8.4	7.9	4.8
Site 31	4.7	6.0	3.8
Site 33	5.6	5.5	4.1
Site 34	2.1	1.5	1.8
Site 35	5.0	3.4	4.0
Site 36	5.9	4.6	5.3
AVE	7.0	6.4	5.2

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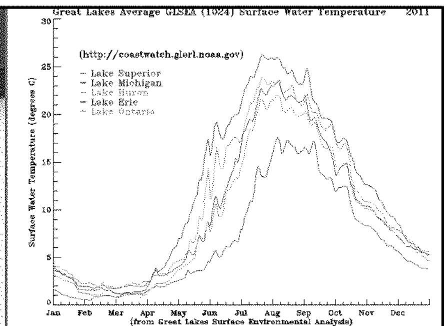
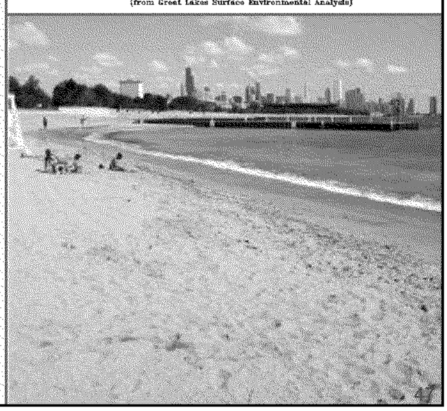
Lead levels were higher in warmer water temperature months

Seasonal Variability
Pb Higher in Warmer Months

- The LCR currently requires 'standard monitoring' to be conducted during two six-month rounds which each include a broad range of water temperatures
  - January through June
  - July through December
- Sampling conducted in colder water months (Mar/Apr) produced lower Pb levels than samples collected in the warmer water months (Sept/Oct)
  - Overall, 68% and 69% of NHU and PF first-draw samples, respectively, were higher in Sept/Oct than in Mar/Apr.

First-Draw Mar/Apr vs. Sept/Oct	Normal Household Use	Pre-Flush
Student's t-Test **P-Value** (two-tailed, paired)	**0.03**	**0.04**





NDWAC Consultation on LCR Revisions

NDWAC Consultation on Potential LCR Revisions

- NDWAC White Paper on Potential LCR Revisions:
  - **Sample Site Selection Criteria**
  - **Lead Sampling Protocol**
  - **Public Education for Copper**
  - **Measures to Ensure Optimal Corrosion Control Treatment**
  - **Lead Service Line Replacement**

NDWAC Website: http://water.epa.gov/drink/ndwac

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Take Home Messages

Take Home Messages

- The current LCR compliance sampling significantly underestimated lead levels
- Care should be taken when performing work to minimize the disturbance of LSLs
  - Provide flushing instructions when LSLs are disturbed (see next slide)
  - Flushing recommendations for homes with LSLs should be updated to avoid increasing consumers' lead exposure.
- Where feasible, removal of LSLs is the best permanent solution
  - AWWA/AMWA: "We support replacement of lead service lines that significantly contribute to high lead levels in the home."
  - LSLs can result in many unintended consequences for other treatment, operational and maintenance activities, as well as compliance complications.

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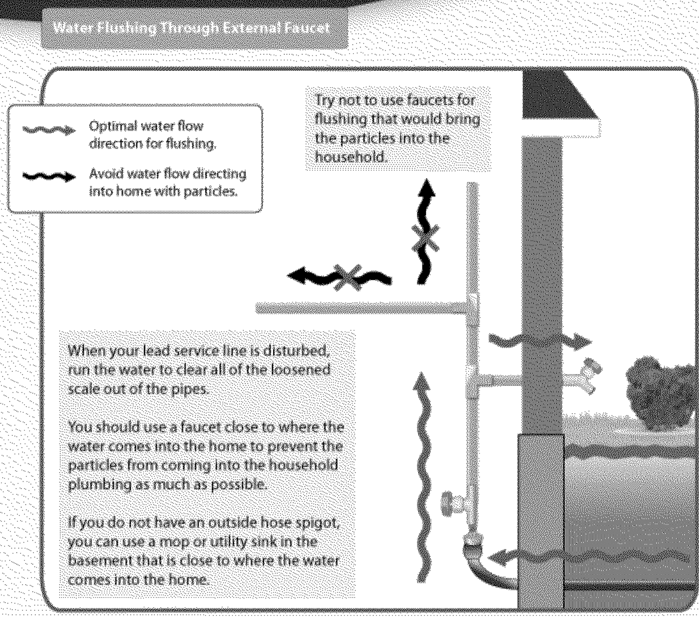
Flushing Advice for homes where LSL is disturbed.



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Take Home Messages

- PWSs **CANNOT** use alternative site selection criteria or LSL sampling for compliance right now
  - LCR site selection and sampling protocol is prescriptive, with no flexibility to change sampling protocol (static since 1991)
  - PWSs **CAN** use alternative site selection criteria and sampling protocols to help optimize corrosion control.
- **Consult with State!**
  - PWSs can incur violations if LCR sampling requirements are not followed for compliance samples.

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Additional Information

For more information on Chicago Lead Sampling Study:
http://www.epa.gov/Region5/water/chicagoserviceline/index.html

- Chicago Lead in Drinking Water Study (download)
- Advice for Residents
- How do I know if I have a LSL
- What do LSLs look like
- Cleaning aerators
- Flushing instructions
- Collecting water samples

Related Journal Article:

Del Toral, M. A., Porter, A., & Schock, M. R. (2013). Detection and Evaluation of Lead Release from Service Lines: A Field Study.*Environmental Science and Technology, 47(16),*9300-9307. doi:10.1021/es4003636

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Questions